THE VARIATIONS OF THE NORMAL KNEE-JERK, AND THEIR RELATION TO THE ACTIVITY OF THE CENTRAL NERVOUS SYSTEM.

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The research described in this paper was made with the purpose of studying the variations to which the knee-jerk is normally subject. The observations reported are based on experiments which were made with a hammer which struck a blow of known force, and with an apparatus that gave an accurate record of the extent of the resulting knee-jerks. The experiments were all made on the writer, who is a healthy man; they extended over six weeks; they were made at two hundred and thirty-nine different times; and they numbered six thousand, six hundred and thirty-nine. Of these experiments only five thousand, four hundred and seventy-six are reported in the tables accompanying this paper.

These experiments demonstrate not only that the extent of the knee-jerk varies with the force of the blow employed, but that when blows of the same force are used the extent of the knee-jerk varies greatly on different days, at different parts of the same day, and even in experiments which rapidly succeed each other.

The cause for these variations in the extent of the knee-jerk are conditions which affect the vigor of the muscles and nerves involved in the process, and,

to a still greater degree, all influences which vary the activity of the central nervous system as a whole, or of special mechanisms of the spinal cord and brain.

Of the many names which have been given to this phenomenon, viz.: "knee phenomenon," "patellar tendon reflex," "myotatic contraction," "knee-kick," "knee-jerk," the last has commended itself to the writer, because it calls attention to the peculiar suddenness of the movement, and does not imply anything with regard to the nature of the process.

The author takes this opportunity to express his thanks to Prof. H. Newell Martin and Professor G. Stanley Hall, for their valuable advice and their great courtesy. He takes pleasure, also, in acknowledging his indebtedness to his co-worker in this research. All the experiments were made upon the writer by his wife, and their value is greatly enhanced by the accuracy and care with which her work was done.

METHOD OF PRODUCING THE KNEE-JERK, AND THE NATURE OF THE PROCESS.—Place the subject in an easy position, with his knee partly flexed, and his leg freely movable; then strike the middle of the ligament, just below the knee pan, a sudden blow. The kick which results has a jerky character, which is quite peculiar.

If a man sits with one leg crossed over the other, the quadriceps muscle of the leg that is uppermost is slightly stretched by the weight of the suspended leg and foot, and the chain composed of the quadriceps tendon, the patella and the patellar ligament, which connects the quadriceps

muscle with the head of the tibia, is subjected to considerable tension. If, now, the ligamentum patellæ be struck, it will be suddenly depressed into the cavity of the joint beneath it, and a jerk will be transmitted by means of the patella and the quadriceps tendon to the quadriceps muscle. Whether the muscle fibres and the motor nerve fibres lying in the muscle are directly stimulated by the mechanical irritation thus brought to them, whether the end organs of the sensory nerves in the end of the tendon near the muscle, and in the muscle itself, are excited by the effect of the blow, and transmit stimuli to the muscle through the afferent spinal nerves, the centers in the spinal cord and the efferent spinal nerves, or whether both of these processes aid to bring about the muscular contraction, is unknown. We only know that the result of the blow is to cause a sudden contraction of the quadriceps, which jerks the foot forward in the characteristic manner.

All the methods by which the knee-jerk may be obtained, are merely different ways of giving the quadriceps muscle a twitch by bringing a sudden strain upon its tendon.

NATURE OF THE PROCESS.—Whatever view is held with regard to the nature of the process, all admit that it is very dependent upon the condition of the reflex arc, and that the only matter of doubt is whether the influence exerted by the spinal cord has the form of a reflex action and occurs after the blow has been struck, or whether it is a continuous reflex influence which prepares the muscle by increasing its tone, and thus renders it more susceptible to the irritation resulting from the

blow. The argument that the time is too short for a reflex act is inconclusive on account of our lack of knowledge of reflex times in general, and the attempt to prove the existence or non-existence of muscle tonus has thus far proved futile. The fact remains, however, that the existence of the knee-jerk is dependent on the integrity of the reflex arc, and, moreover, that the extent of the knee-jerk is greatly influenced by the irritability of the spinal cord.

Causes for Variations in the Extent of the Knee-Jerk.—It is not the intention of the writer to offer the results recorded in this paper as laws applicable to all men. The influences which determine the extent of the knee-jerk are far too numerous and too subtle to be ascertained by a few thousand experiments on any one man. Although, as has been said, the nature of the knee-jerk is not thoroughly understood, we know it to be an elaborate physiological process, involving the action of many different organs, for both experimentation and clinical experience have disclosed that the normal activity of the quadriceps muscle, of the corresponding afferent and efferent spinal nerves and their roots, and of a certain portion of the cord are necessary to its completeness. Since every condition which influences the action of these different organs must necessarily have its effect upon the extent of the knee-jerk, it is not strange that the phenomenon is subject to many variations. This becomes the more apparent if one considers how many influences are continually modifying the activity of nerve and muscle tissue, and, still more, of the delicate mechanisms of the central nervous

system. Not a few of these changes have their origin in the influence exerted by the different parts of the central nervous system on each other, and there can be but little doubt that the mutual dependence of the cerebro-spinal centers is much greater than has generally been supposed. Indeed, it would almost seem as if the nervous connections were so intimate that a change in the activity of any one of these centers would make itself felt in all the rest, as if, to speak figuratively, there were a balancing of nervous tension throughout the nervous system, so that a change in any one part must be felt in all other parts. Thus, though an increase in pressure, due to a sudden production of nerve force, might, perhaps, encounter less resistance, and so make itself felt chiefly in certain directions, it would produce a slight effect throughout the whole system. The picture represents a condition of things similar to that existing in the circulatory system, where a change of pressure brought about at any part tends to be transmitted to all the rest. Far be it from the writer to offer or support a theory of the action of what we call nerve force. The line of thought has been suggested, however, by the results of his own and similar experiments, which have shown that a strong sensory irritation, a voluntary action, or even an emotion, is sufficient to influence the extent of the knee-jerk. It has long been known that the nervous system binds the many organs of the body into a whole, and that through it the condition of every part is made to have its influence on all the rest, but the closeness of this union has never been illustrated with such startling distinctness as it is in the incessant variations of the knee-jerk.

THE DIAGNOSTIC IMPORTANCE OF THE KNEE-JERK. It is now nine years since Westphal and Erb proclaimed the absence of the knee-jerk in Tabes Dorsalis, and during this time physicians have come to regard the test as a part of the regular routine of physical diagnosis. Nevertheless they have never been quite satisfied with it. In spite of the fact that Berger reported, as a result of the examination of 1409 healthy individuals, that it was absent in only 1.56 per cent., and that Bernhardt stated that he had found it absent in all but two of forty-six cases of Tabes, which he had studied, there have been so many contradictory reports in medical journals, and every practitioner has found so much difficulty in getting satisfactory results in the doubtful cases, that the knee-jerk has been gradually drifting into disfavor. It is probable that a reaction is at hand, for the discoveries of the past four years offer an explanation of many of the apparently inexplicable results, and at the same time greatly extend the usefulness of the symptom.

REËNFORCEMENT OF THE KNEE-JERK.—In 1883 Ernst Jendrassik[1] reported his observation that if the hands were clinched just before the ligamentum patellæ was struck, the resulting knee-jerk was greater than it was when the subject was quiet.

Jendrassik's interesting discovery was made the subject of the most careful study by Dr. S. Weir Mitchell and Dr. Morris J. Lewis,[2] and they were

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[1]Beiträge zur Lehre von den Schnenreflexen.—Deutsches Archiv. f. klin. Med. Bd. 33, s. 177, 1883.

[2]Physiological Studies of the Knee-jerk and of the Reactions of Muscles under Mechanical and other Excitants.—*The Philadelphia Medical News*, Feb. 13 and 20, 1886.

able, not only to corroborate his results, but to show that the knee-jerk was subject to the most extensive variations, even during health, and that these variations probably occurred by means of alterations in the activity of the nerve centres, upon whose integrity the knee-jerk has been found to be dependent. Although the work of these observers is, as far as the writer has been able to test it, correct in every particular, it has been received with a certain amount of scepticism, because their remarkable results are based on observation alone, and not upon any record which can be a proof to others. It is, indeed, wonderful that, trusting as they did to the ability of the hand to deliver a series of blows of constant force, and to the eye to observe slight differences in the extent of the knee-jerk, they should have been able to discover so many facts and to prophesy truly the discovery of so many others. Men who have not their keen power of observation obtain their results with difficulty, and regard them with doubt, and are half inclined to deny all except the results that can be obtained by the coarsest experiments.

THE EXPERIMENTS OF THE AUTHOR.

It seemed to the author that before the knee-jerk could take its proper place as an aid to physical diagnosis, or, still more, as a means of investigating the influences which affect the activity of the central nervous system, there must be devised, first, a method of striking the ligamentum patellæ a blow of known force, and, second, a method of recording the extent of the resulting knee-jerk. If one could be sure of giving the same stimulus throughout a

large series of experiments, and could obtain records of the resulting movements of the leg, one could definitely determine the limits of the normal knee-jerk and the variations which it undergoes under normal conditions. With these thoughts in mind the writer entered upon the research recorded in this paper.

THE APPARATUS EMPLOYED.

1. *A hammer by which it was possible to strike a blow of any desired force.* (See Plate I, Fig. 1.)—Several methods suggested themselves by which one might strike the ligamentum patellæ a blow of any desired force. Of these, the one which upon trial commended itself most highly, was to suspend a hammer by an axis passed through its handle. The hammer could then be made to fall like a pendulum, and would strike a blow, the force of which would depend on the weight of the hammer and on the height from which it fell.

Two instruments of nearly the same construction were employed, the one in the first series of experiments, the other in the second series.[1] The construction of these instruments is shown in Fig. 1, and was in general as follows:

The head of the hammer, *a*, which was made of iron, was 10.5 cm. long, 2.5 cm. wide, and 2.5 cm. thick, and weighed 346.5 gms. It was narrowed at either end to a smooth rounded edge, one of these edges being vertical and the other horizontal.

The handle of the hammer, *b*, a steel rod 22 cm. long and 1 cm. in diameter, weighing 100 gms., passed through a hole which was bored vertically through the middle of the head of the hammer, and protruded a few mm. from the lower side of the head, *c*. The head was fastened to the handle by a screw; and it was so placed that its middle point was just 20 cm. distant from the middle of the axis, which supported the hammer.

The axis, *d*, passed through the handle of the hammer as close as possible to its upper end. It was a steel rod, 5 cm. long and 5 mm. in diameter, and it was pivoted at either end on steel points. The handle was fastened to the axis at about 1 cm. from its inner end.

The screws, *e e*, on which the axis was pivoted, were held by two heavy pieces of brass, *f f*, which extended downward from the horizontal steel rod, *g g*, which supported the whole apparatus, and which was itself clamped at any desired height, on a substantial standard, with a heavy iron base.

A brass plate, *h*, 2.5 mm. thick, was fastened by its upper left hand corner to the supporting rod and to the back of the heavy piece of brass which held the inner pivot, in a plane parallel to that cut by the handle of the hammer when it fell, and with its face

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[1]One of these hammers was made, through the kindness of Prof. H. Newell Martin, by the mechanic at the Biological Laboratory, the other by Lehman, instrument maker, Baltimore.

looking toward the hammer. The left edge of the plate was vertical, the upper edge horizontal, and the right and lower borders formed an arc whose centre would be cut by a line drawn through the pivots supporting the axis of the hammers. A scale of 90° was engraved on this plate a centimeter from its curved edge, and in such a way that 0° corresponded to the middle of the handle of the hammer when it was hanging in the position determined by the force of gravity.

On the back of this plate and parallel to its surface there swung from an axis, whose centre would be cut by a line drawn through the pivots supporting the axis of the hammer, a heavy strip of brass, *i*, 3.5 mm. thick, 25.5 cm. long and 2.5 cm. wide.

This swinging arm bore on its face a small brass plate, *k*, which had a lip which slightly lapped over the curved border of the plate on which the scale was engraved. This small plate was held in place on the arm by two pins and a thumb screw, *l*, which had its head on the back of the arm. When the thumb screw was screwed home it pressed the lip, like a clamp, tightly down on the border of the large plate at any desired place. This clamp bore on the middle of its face an index, *m*, the point of which was directed to the scale engraved on the large plate and determined the position of the arm.

The free end of the arm terminated in a catch, by means of which the hammer could be held and easily be released whenever it was desired. This catch had the following construction viz.: A heavy block of brass, *n*, was fastened to the end of the arm in such a position that the end of the handle of the hammer which protruded beyond the head would just swing clear of its upper surface. A steel spring forced a small steel catch, *o*, up through a hole in the brass block, so that it projected slightly beyond the surface and obstructed the fall of the hammer by catching the handle where it protruded from the head. The lower part of the block of brass was cut away, so as to make room for a lever, *p*, which had the shape of an inverted L, and which was pivoted at the end of its short arm on the lower end of the catch, and again at the place where the two arms of the L meet, to the solid brass block. By means of this lever the catch could be drawn down and the hammer released.

In all the experiments reported in this paper the subject was reclining, with outstretched leg, (see Fig. 2,) and inasmuch as the ligamentum patellæ was horizontal, the blow was struck with the vertical edge of the hammer. In certain other experiments, in which the subject sat with dangling legs, the ligament held a vertical position and the head of the hammer had to be turned around and its horizontal edge used.

2. *The couch and the supports for the thigh and foot.*[1]—See Plate I, Fig. 2, *a*.)—The following arrangements were made, first, to insure the subject an absolutely comfortable position and freedom from all avoidable reënforcing influences; second, to relieve the quadriceps muscle from the weight of the foot, and so permit its slightest contraction to produce a visible movement.

The man experimented upon lay on his left side, upon a comfort-

[1]These arrangements were the same as those employed by the writer in a previous research, viz.: "Is the Knee-Kick a Reflex Act?"—*The Amer. Jour. of Med. Sciences*, Jan., 1887.

able couch, so formed as to support the back and head. (See Fig. 2.) The right thigh rested in a splint of plaster of Paris, shaped so as to conform to inner and posterior surface, and of such a height as to hold the right knee on a level with the hip joint. The right foot was supported at the same height by a swing suspended by a long cord from the ceiling.

3. *The recording apparatus.*—(See Plate I, Fig. 2, *b.*)—The amount of the knee-jerk was revealed in the movement of the foot which it produced, and the extent of this movement was automatically recorded.

A long, light but stiff steel rod extended horizontally backward from the awning on which the foot rested, and at right angles to the lower leg. It was fastened to the back of the swing by a ball and socket-joint and it rested, near its free end, in the groove in the circumference of a wheel, which turned so easily as to rotate under the weight of the rod when the latter was pulled forward or pushed backward by the swinging foot.

A steel needle was fastened on the rod at right angles to it, and wrote with its point on a sheet of glazed paper which had been stretched on a board, blackened by the soot of a gas flame, and placed horizontally at a short distance below the horizontal rod. As the foot was jerked forward by the sudden contraction of the quadriceps muscle, following the blow on the ligament, the needle was dragged across the blackened paper and wrote the extent of the movement. As the muscle relaxed again the foot swung back to its original position, *i. e.*, that which was determined by the balancing of the tension of the antagonistic flexors and extensors of the knee.

The under surface of the board on which the paper was stretched was crossed by two parallel grooves, which corresponded to two glass tracks on the little table on which the board rested. After each experiment the board was made to slide a little to one side, so as to bring a fresh surface of the paper under the needle. The mark made by the needle when the board was thus moved recorded the position of the foot when all was quiet and gave a base line from which to measure the extent of the movements of the foot. At the end of the experiments the records thus obtained were "fixed" by being passed through an alcoholic solution of brown shellac, and the distance moved by the foot as a result of each knee-jerk was measured in mm. and tabulated.

In the experiments in which the effect of respiration on the knee-jerk was studied it was necessary that the record should be made on a moving surface, and therefore the blackened paper was stretched on the drum of a Kymographion.

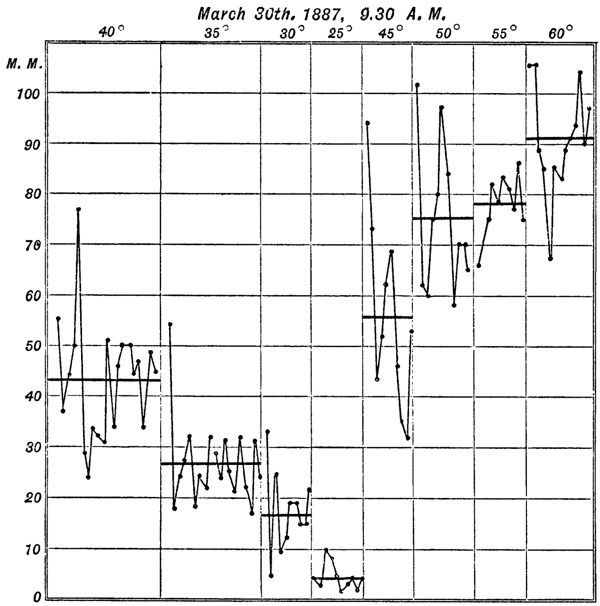
The Experiments.

Effect of successive blows of the same and of different strengths.—The first experiments made with the apparatus described were to determine

how far the extent of the knee-jerk is dependent on the force of the blow. No one who has ever tried to call out the phenomenon can have any doubt that its amount varies with the force of the blow, but in our experiments the closeness of the relation did not at once appear, because we were confronted forthwith by the puzzle which has faced us throughout our work, and which still remains, to a great extent, undeciphered. We found, namely, that if a number of blows of the same force were struck at definite intervals, from exactly the same direction, and on the same part of the ligamentum patellæ, no two of the resulting knee-jerks were of the same extent. Naturally, the sources of reënforcement described by Dr. L. Weir Mitchell and Dr. Morris J. Lewis were looked to for an explanation, but none such could be found. The subject was lying completely at rest in a comfortable position and was conscious of no irritation. His eyes were closed, all the muscles were passive, and the whole body was, as far as possible, in a state of rest. It was then suggested that the force of the blow be increased. This was done, and though similar variations in the extent of the knee-jerk were seen, the movements were found, as a whole, to be greater than before. It was soon ascertained that though blows of the same strength called forth knee-jerks of very different amounts, the averages gained from several groups of twenty or more experiments each, made by striking blows of a certain force, were almost exactly the same, and furthermore, that if the force of the blow was altered, the averages of such groups of experiments made with blows of different strengths, were greater or less, according as the force of the

blow had been increased or decreased. These results will be better understood by reference to Fig. 1.

Fig. 1.



The base line, *o*, shows the position of the recording needle when the leg is quiet, and each of the dots connected by the curve shows, in millimetres, the distance which the foot moved as a result of a blow on the ligamentum patellæ. The experiments which are grouped together show how different may be the extent of the knee-jerks which are obtained by blows which have the same force and which are produced by letting the hammer fall through an arc of the number of degrees given at the top of the table. The heavy horizontal lines which cross such groups indicate the average of the enclosed experiments.

Search for errors in the method employed.—The fact that blows of the same force evoked knee-jerks of very variable extent was, as has been said, an entire surprise to us. The most careful examination failed to reveal any mechanical cause. The hammer fell from exactly the same height and was released in just the same way each time, and as

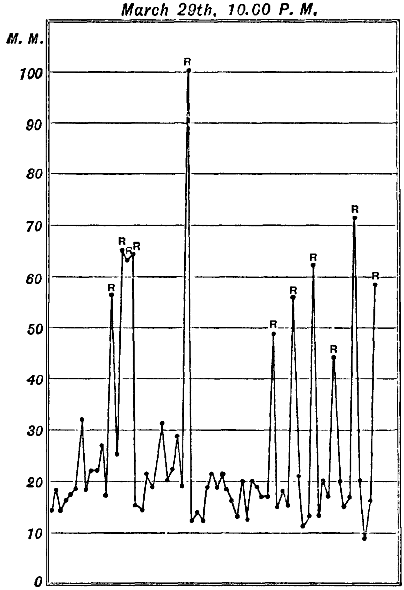
there was no appreciable friction in the apparatus, there could be no doubt that it gave a blow of definite force. The blows were delivered at intervals of fifteen seconds; therefore, the variations could not be due to a wearying of the muscle. Moreover, the knee-jerk was often greater at the end of a series of experiments than at the beginning. The only chance for error seemed to lie in the possibility that the position of the leg was changed slightly from time to time, and that the hammer did not strike the ligament at exactly the same place each time. This question was carefully studied and we were unable to find that there was any such change of position. Moreover, we discovered that it made no appreciable difference in the extent of the knee-jerk whether the hammer struck exactly the middle of the ligament, as we always tried to have it do, or a little above or below that point. Having ruled out all possible sources of error, we were compelled to conclude that the variations which we saw were due to changes which occurred within the individual and which reënforced the action of the mechanisms which produce the knee-jerk. Succeeding experiments proved that there was no lack of reënforcing influences.

The variations seen were compared with strongly reënforced knee-jerks.—Having once assumed that the variations which we had seen were due to some reënforcing influence, we had the curiosity to compare the largest of the knee-jerks, obtained when the subject was entirely quiet, with those which should result from some of the vigorous forms of reënforcement, described by Mitchell and Lewis, such as clinching the hands or clinching the teeth. The results of a few experiments, in

which the reënforcements caused by clinching the teeth were compared with knee-jerks obtained during rest, are shown in Fig. 2. Had a still more active form of reënforcement been employed, probably still greater differences would have been seen. The reënforced knee-jerks, which resulted from voluntarily clinching the teeth, were so extensive as to convince us that the unknown sources of reenforcement, which were continually influencing the knee-jerk, were comparatively weak phenomena.

Fig. 2.

March 29th, 10.00 P. M.



Aim of Experiments of Series I.—It was a great temptation to us to immediately begin to study the effects of different methods of reënforcing the knee-jerk, but we resisted the impulse, knowing that it was much more important to lay a sure foundation for such work by patient and careful study of the extent of the normal knee-jerk when not subject to such exciting influences. We, therefore, determined to make a series of experiments which should last over many days, and which should determine the extent of the knee-jerk in the case of one man who was well, and who was leading his usual regular life. We could not help hoping that in

the course of such experiments many of the more ordinary forms of reënforcement would reveal themselves to us.

Routine of Experiments.—Such a research was accordingly undertaken. The experiments were made on the writer. They extended from April 1st to April 14th inclusive.[1] The condition of the knee-jerk was examined seven times a day, and twenty-five experiments were made at each examination. The hours chosen for the experiments were as follows, viz.: 8.15 A. M., immediately upon rising; 9.15 A. M., soon after breakfast; 1.15 P. M., just before lunch; 2.15 P. M., just after lunch; 6.15 P. M., just before dinner; 8.00 P. M., soon after dinner; and 11 P. M., just before going to bed. For various reasons it was not always possible to make the experiments at exactly the schedule time, but it was seldom that the time of the experiment varied half an hour from that given. The total number of examinations in this series was 93, and the total number of experiments was 2,321. The many experiments which were made at other than the schedule times are not included in these figures.

In the case of each experiment, the hammer was so placed that, when it was hanging free, it just touched the skin over the middle of the ligament. It was then raised through an arc of 40° and allowed to rest on the catch. At the proper moment it was

[1]Throughout the period the subject led a regular life, getting up and going to bed at his usual hours, doing his ordinary work and eating his accustomed fare. It is worth noting that no wine or beer was used during the period, but that a cup of coffee was taken with breakfast and dinner, and a cup of tea with lunch. The subject, as was his habit, smoked one or two cigars a day.

released by a slight movement of the lever, and, inasmuch as it always fell from the same height, it always struck a blow of the same force. The blows were given at intervals of fifteen seconds, and they struck the same part of the ligament each time. For the sake of accuracy all the experiments were made on the bare leg, although examination showed that nearly the same results could be obtained when the knee was covered by a thin layer of clothing. Throughout all the experiments the subject lay with closed eyes, in an absolutely comfortable position, and, as far as was possible, not only avoided all voluntary movements, but directed his thoughts away from the experiment and to some indifferent subject. During the earlier experiments the blows of the hammer were each distinctly felt, but later they were often scarcely noticed, and in many cases the subject went, before the end of the examination, almost, if not quite, asleep.

The following tables give, as far as possible, an accurate account of the experiments and of the condition of the subject at the time that each examination was made. The extent of the movement of the foot resulting from each knee-jerk was accurately measured in millimeters, and tabulated; inasmuch, however, as the reader can be given no correct idea of the subtler influences which governed the extent of each separate knee-jerk, it does not seem profitable to report all these measurements, and only the average of the experiments made at each examination is given. In most cases, indeed, the more delicate influences which determined the extent of the knee-jerk remained undiscovered, but, at times, they unexpectedly revealed themselves, and these discov-

eries give a most interesting and important addition to the physiology of the knee-jerk, and of the central nervous system. These results will be reported by themselves later in the paper.

Explanation of the Tables.—Each table is made in three parts; the first, headed Knee-Jerk, contains the results of the experiments; the second, headed Extracts from Journal, gives, in brief, the way in which the subject spent the day, and, therefore, an idea of his condition at the time of the examination; and the third part, headed U. S. A. Weather Observations, reports the condition of the weather in the morning, afternoon and evening. In the first column of the first part of the table, the time at which the examinations were made are set down; in the second column, the number of experiments made at each time is reported; in the third is recorded in millimetres the average extent of the knee-jerk as determined by these experiments; in the fourth are shown the least and greatest knee-jerks got in the examination, and in the fifth is stated, in the number of degrees through which the hammer fell, the least blow by which a recognizable knee-jerk could be obtained. At the bottom of column two the total number of the experiments made during the day is given; next to this, under column three, is written the average knee-jerk for the day, as determined by the total number of experiments; by the side of this are noted the extreme variations of the knee-jerk obtained on this day with the blow of standard force, *i. e.*, when the hammer fell through an arc of 40°; and, finally, under column five, one is told what was the least blow which was capable, at any time during the day, of producing a visible knee-jerk.

No. 1, Series I—April 1st, 1887.

Knee-Jerk.					Extracts From Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest Effective Blow.	Well and Vigorous.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.30 a.m.	25	36	20–48	27°	Just out of bed and half asleep.	7 a.m.	30.150	31°	84	n.	lt. snow
9.45 "	18	88	55–120	20°	Just after breakfast.						
1.15 p.m.	12	111	90–130	20°	Morning spent writing.						
2.15 "	20	68	29–93	23°	Just after lunch.	3 p.m.	30.089	36°	87	n.e.	lt. snow
6.15 "	23	49	10–78	26°	Afternoon spent writing, head tired.						
8.15 "	26	44	16–75	29°	Just after dinner.						
10.30 "	25	45	22–60	30°	Evening spent reading and writing.	10 p.m.	30.036	34°	88	n.	lt. snow
	149	63	10–130	25°		mean.	30.092	34°			

No. 2, Series I—April 2d, 1887.

Knee-Jerk.					Extracts from Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest Effective Blow.	Well, but somewhat fatigued by yesterday's work.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.15 a.m.	26	28	12–42	29°	Just out of bed—sleep again (?)	7 a.m.	29.907	34°	89	n.w.	lt. snow
9.45 "	24	72	45–93	26°	After breakfast.						
1.15 p.m.	23	63	31–94	24°	Morning spent writing.						
2.30 "	27	52	26–75	28°	Just after lunch.	3 p.m.	29.789	52°	38	n.w.	clear.
6.15 "	22	23	7–50	35°	Afternoon spent writing—walk an hour.						
8.15 "	27	33	9–62	30°	Just after dinner.						
10.30 "	20	58	37–91	30°	Ev'g spent reading German with friends	10 p.m.	29.941	46°	38	n.	clear.
	169	47	7–94	29°		mean.	29.879	44°			

No. 3, Series I—April 3d (Sunday), 1887.

Knee-Jerk.					Extracts From Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest Effective Blow.	Well, but feel lazy.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
9.30 a.m.	25	40	33–52	25°	Just out of bed; been awake an hour.	7 a.m.	30.093	43°	55	n.w.	clear.
10.15 "	24	64	45–80	26°	Just after breakfast.						
2.15 p.m.	27	39	21–65	28°	Morning spent writing and reading; no hard work done.						
3.30 "	25	74	39–103	25°	Just after dinner.	3 p.m.	29.992	64°	34	s.w.	clear.
6.15 "	27	33	9–61	30°	Immediately upon return from stroll of two hours.						
7.30 "	24	57	27–88	25°	Just after tea.						
10.45 "	26	18	8–30	35°	Evening spent writing and talking.	10 p.m.	29.980	49°	66	w.	clear.
	178	47	8–103	28°		mean.	30.022	52°			

No. 4, Series I—April 4th, 1887.

Knee-Jerk.					Extracts From Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest Effective Blow.	More rested than yesterday. An enervating day.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.15 a.m.	25	31	7–49	32°	Just out of bed and very sleepy.	7 a.m.	29.928	48°	74	s.	clear.
9.15 "	25	73	43–100	26°	Just after breakfast.						
1.15 p.m.	25	20	6–39	34°	On my feet somewhat—read and talk.						
2.15 "	25	24	7–48	30°	Just after lunch.	3 p.m.	29.724	76°	28	s.w.	clear.
6.15 "	25	27	11–44	36°	Afternoon at laboratory.						
9.20 "	27	21	10–42	37°	An hour after dinner.						
11.00 "	25	22	10–31	37°	A quiet and restful evening.	10 p.m.	29.771	58°	61	n.w.	cloudy
	177	31	6–100	33°		mean.	29.808	61°			

No. 5, Series I—April 5th, 1887.

Knee-Jerk.					Extracts From Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest Effective Blow.	Well, but not very energetic.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.15 a.m.	21	19	10–30	35°	Just out of bed and very sleepy.	7 a.m.	29.908	45°	41	n.w.	fair.
9.15 "	25	51	42–60	30°	Soon after breakfast.						
1.30 p.m.	13	27	14–47	32°	Morning spent writing.						
2.30 "	25	43	21–75	27°	Soon after lunch.	3 p.m.	30.019	38°	59	n.w.	cloudy.
6.30 "					Wrote till five, then walked an hour.						
7.45 "	24	57	4–82	29°	Just after dinner.						
10.30 "	27	23	12–41	35°	Walk and make a call; read aloud.	10 p.m.	30.187	31°	50	n.w.	clear.
	135	37	4–82	31°		mean.	30.038	38°			

No. 6, Series I—April 6th, 1887.

Knee-Jerk.					Extracts From Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimeters.	Extremes.	Lightest Effective Blow.	Well.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.15 a.m.	25	23	12–38	31°	Just out of bed.	7 a.m.	29–332	32°	61	n.w.	fair.
8.30 "	25	51	31–72	27°	Before breakfast and after bath.						
9.30 "	24	79	56–105	25°	Just after breakfast.						
1.15 p.m.	25	49	20–70	27°	Morning spent in making a call and writing.						
2.30 "	26	54	25–82	26°	Just after lunch.	3 p.m.	30–300	48°	26	n. w.	clear.
6.15 "	25	15	7–31	37°	Afternoon spent standing and talking.						
8.00 "	24	32	12–54	30°	Just after dinner.						
11.00 "	24	29	18–55	37°	Evening spent in reading German with friends. At 10.30 the music experiment.	10 p.m.	30.352	41°	39	s.	clear.
	198	47	7–105	34°		mean.	30.328	40°			

No. 7, Series I—April 7th, 1887.

Knee-Jerk.					Extracts From Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimeters.	Extremes.	Lightest Effective Blow.	In morning feel well and vigorous, but become nervous by noon, so that I start easily at noises.	Time.	Barometer.	Thermometer.	Relative Humidity	Wind.	Weather.
8.15 a.m.	26	29	18–38	36°	Just out of bed.	7 a.m.	29.437	38°	60	n.	cloudy
9.30 a.m.	25	71	45–96	22°	After breakfast and an earnest talk.						
1.15 p.m.	24	66	39–92	22°	Morning spent writing—head dizzy.						
2.15 "	25	34	9–57	25°	Just after lunch.	3 p.m.	30.442	50°	34	e.	cloudy
6.30 "	25	31	10–75	30°	Afternoon spent writing; walk half an hour; head and eyes tired.						
8.00 "	25	52	32–72	29°	After dinner and an earnest talk.						
11.00 "	25	32	18–58	32°	Write till ten, then read aloud an hour.	10 p.m.	30.552	45°	60	e.	cloudy
	175	45	9–96	28°		mean.	30.477	44°			

No. 8, Series I—April 8th, 1887.

Knee-Jerk.					Extracts from Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest Effective Blow.	Well, slightly tired.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.45 a.m.	25	22	7–40	37°	Just out of bed.	7 a.m.	29.680	41°	66	n.e.	cloudy
9.45 "	25	70	53–87	27°	Just after breakfast.						
1.15 p.m.	28	29	5–87	31°	Wrote a short time; took a walk.						
2.15 "	25	42	17–71	27°	Just after lunch.	3 p.m.	30.566	54°	41	s.e.	clear.
6.15 "	25	44	29–74	22°	Write, call, write.						
8.30 "	28	51	30–72	25°	Just after dinner.						
11.30 "	27	43	22–68	30°	A quiet evening.	10 p.m.	30.536	45°	55	s.	clear.
	183	43	5–87	28°		mean.	30.577	46°			

No. 9, Series I—April 9th, 1887.

Knee-Jerk.					Extracts From Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lighest Effective Blow.	Well and vigorous.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.00 a.m.	26	35	15–50	28°	Just out of bed.	7 a.m.	30.525	39°	80	s.	clear.
9.00 "	25	71	48–100	26°	Just after breakfast.						
1.15 p.m.	26	37	11–72	27°	A busy morning; head and back ache.						
2.15 "	25	36	13–64	26°	Just after lunch.	3 p.m.	30.348	61°	54	s.e.	clear.
6.15 "	25	21	8–49	35°	Afternoon spent writing; walk an hour.						
8.15 "	26	33	15–68	31°	Just after dinner.						
10.30 "	25	14	7–27		A walk; read; evening is close.	10 p.m.	30.276	51°	61	s.	clear.
	178	35	7–100	29°		mean.	30.383	50°			

No. 10, Series I—Sunday, April 10th, 1887.

Knee-Jerk.					Extracts From Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest Effective Blow.	Well.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.15 a.m.	25	13	6–31	39°	Just out of bed.	7 a.m.	30.212	45°	59	s.	clear.
9.30 "	25	53	30–74	31°	Soon after breakfast.						
1.30 p.m.	25	26	5–71	33°	Church; a short walk.						
3.30 "	26	44	17–76		Soon after dinner.	3 p.m.	30.093	83°	25	n.w.	clear.
7.45 "	16	31	18–52		After a walk of two hours.						
11 "	27	17	6–39	37°	After a quiet evening.	10 p.m.	30.077	65°	48		clear.
	144	31	5–76	35°		mean.	30.127	67°			

No. 11, Series I—April 11th, 1887.

Knee-Jerk.					Extracts from Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest Effective Blow.	Well; seminal emission early this morning.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.15 a.m.	25	9	4–27	39°	Just out of bed.	7 a.m.	30.108	61°	49	w.	clear.
9.30 "	25	40	12–56	30°	Soon after breakfast.						
1.15 p.m.	25	23	5–61	35°	Morning spent writing and talking.						
2.30 "	25	41	21–69	30°	Just after lunch.	3 p.m.	30.024	83°	23	w.	clear.
6.15 "	25	27	0–50	33°	Afternoon spent writing.						
8.00 "	26	25	10–57	35°	Just after dinner.						
11.15 "	25	20	9–32	36°	A walk; listen to reading.	10 p.m.	30.097	72°	34	n.w.	clear.
	176	27	0–69	34°		mean.	30.076	72°			

No. 12, Series I—April 12th, 1887.

Knee-Jerk.					Extracts From Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest Effective Blow.	Well.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.30 a.m.	27	20	3–42	37°	Just out of bed and very sleepy.	7 a.m.	30.273	58°	67	n.e.	clear.
9.30 "	25	57	38–78	27°	Just after breakfast.						
1.15 p.m.	26	21	9–41	33°	Morning spent standing and walking.						
2.30 "	21	42	25–60	29°	Soon after lunch.	3 p.m.	30.216	65°	52	s.e.	clear.
6.15 "	25	29	6–65	33°	Afternoon at laboratory. On my feet much of the time.						
8 "	25	34	16–71	30°	Soon after dinner.						
12 "	16	10	3–24	33°	Evening with friends. Walk a mile.	10 p.m.	30.253	51°	68	e.	fair.
	165	30	3–78	32°		mean.	30.247	58°			

No. 13, Series I—April 13th, 1887.

Knee-Jerk.					Extracts from Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest Effective Blow.	Well.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.45 a.m.	24	25	11–50	31°	Just out of bed.	7 a.m.	30.295	47°	89	e.	cloudy.
9.30 "	15	74	57–106	22°	Soon after breakfast.						
1.00 p.m.	24	44	25–71	26°	A busy morning.						
2.30 "	25	46	24–69		Soon after lunch.	3 p.m.	30.266	58°	59	s.e.	clear.
6.30 "	25	42	13–74	25°	Afternoon spent writing.						
8.00 "	25	50	27–76	25°	Just after dinner.						
11.00 "	29	20	3–41	33°	Evening spent with friends.	10 p.m.	30.351	46°	64	s.e.	fair.
	167	43	3–106	27°		mean.	30.304	41°			

No. 14, Series I—April 14th, 1887.

Knee-Jerk.					Extracts from Journal.	U. S. A. Weather Observations.					
Time of Examination.	No. of Experiments.	Average Movement in Millimetres.	Extremes.	Lightest effective Blow.	Well.	Time.	Barometer.	Thermometer.	Relative Humidity.	Wind.	Weather.
8.30 a.m.	27	20	7–42	35°	Just out of bed.	7 a.m.	30.317	44°	67	s.e.	fair.
9.15 "	25	53	33–79	20°	Just after breakfast.						
1.15 p.m.	25	42	14–64	24°	Morning spent writing.						
1.45 "	25	41	26–64	25°	After lunch.	3 p.m.	30.184	56°	43	s.e.	clear.
6.30 "	24	16	3–33	34°	Wrote till five; walked an hour.						
8.15 "	25	36	16–64	30°	Just after dinner.	10 p.m.	30.140	49°	65	s.e.	clear.
	151	35	3–79	28°		mean.	30.216	50°			

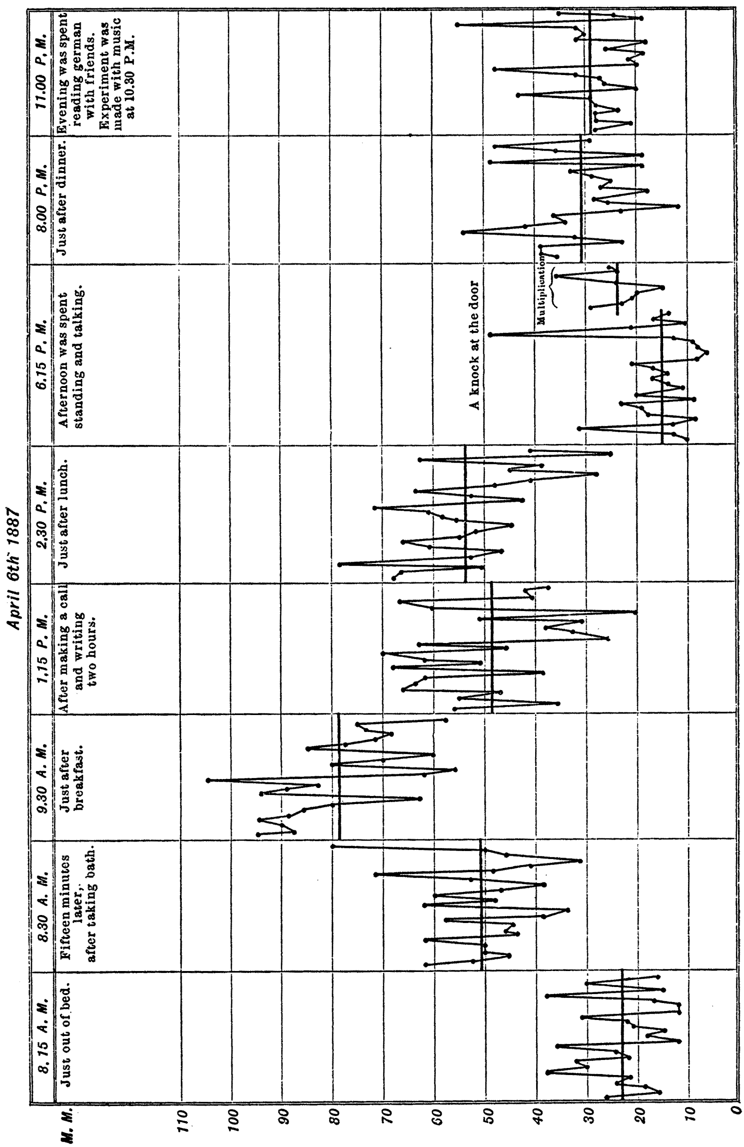
Common experience teaches that when one is well, there are three principal influences which lower the activity of the body: fatigue, hunger and depressing weather; while rest, a meal and invigorating weather increase the activity. One has also learned that even when the general condition is depressed by these influences it may be temporarily roused by any cause of mental excitement, and that when it is in a vigorous state it may be temporarily lowered by drowsiness.

Substitute in the above statements knee-jerk for activity of the body, and they will be equally true. These facts were illustrated in our experiments by a diurnal decline of the knee-jerk, interrupted at meal time, and varied by changes in the weather, fatigue, and by causes of mental excitement.

Explanation of the chart, Fig. 3, which shows all the variations of the knee-jerk which occurred in the course of one day of this series of experiments.— Before studying the results of the experiments as a whole, the writer wishes to illustrate still more clearly the great number of variations to which the knee-jerk is subject in the course of a single day.

The following chart shows the extent of the movement of the foot in millimetres in each experiment taken in the course of one day. All the experiments made at the time of one examination are grouped together under the figures which show the time at which the examination was made. Each dot represents a separate knee-jerk, and the connecting lines are given to enable the eye to more readily grasp the extent of the variations. The heavy horizontal lines show the average of all the experiments through which they are drawn. At the top of the table is given roughly the day's journal, and in the body of the table are remarks accounting for reënforcements, the causes of which were thought to have been recognized.

Fig. 3.


April 6th 1887
8.15 A. M.
Just out of bed.
8.30 A. M.
Fifteen minutes later, after taking bath.
9.30 A. M.
Just after breakfast.
1.15 P. M.
After making a call and writing two hours.
2.30 P. M.
Just after lunch.
6.15 P. M.
Afternoon was spent standing and talking.
8.00 P. M.
Just after dinner.
11.00 P. M.
Evening was spent reading german with friends. Experiment was made with music at 10.30 P.M.
A knock at the door
Multiplication
M. M.
110
100
90
80
70
60
50
40
30
20
10
0

Study of the Chart.—At a glance one sees that, at whatever time the examination was made, the extent of the knee-jerk varied greatly in succeeding experiments. He also notices that the average of the experiments made when the subject was just out of bed, and not thoroughly roused, was low; that in the examination made fifteen minutes later, after the bath had been taken, it was higher; and that an hour later, immediately after breakfast, it was still higher. From this time on, however, the knee-jerk declined, being considerably lower before lunch, and though slightly higher just after lunch, being very much lower just before dinner. After dinner it recovered somewhat, but only to fall again, if but slightly, and at bed time it was very much less than it was just after breakfast, and even less than it was just after the bath taken before breakfast.

To judge from this one day, then, there is a great difference in the extent of the knee-jerk, even in succeeding experiments, and a still greater difference between experiments taken at different times in the day, the knee-jerk being greatest immediately after breakfast, and, in spite of the fact that each meal tends to increase it, being much lower at bed time.

The discussion of the reënforcements which were observed during this day will be deferred until later in the paper.

Diurnal Variation of the Knee-Jerk.—Is the diurnal variation of the knee-jerk seen on April 6th a constant phenomenon? This question is answered by the following table of the averages, compiled from all the experiments which were taken in this series·

Explanation of the Table.—In the first column of the table is given the date of the experiments, and in the first line the hours of the day at which the examinations were made. Beneath the hours, on the same line with the dates, is arranged the average of all the experiments made in the seven examinations of the corresponding day. The table, therefore, enables one readily to compare the results of all the experiments made on each day and of all the experiments made at the same hour on different days. At the bottom of the table, under the hours, is given the average of all the experiments taken at the same hour on all the different days of the series. In addition to this, the table shows the average extent of the knee-jerk for each day; the number of examinations and experiments which were made on each day; and the mean of the barometer and thermometer for each day. Finally, at the bottom of the table, beneath these columns, is placed the average knee-jerk, as determined by all the experiments in the series, and the mean barometer and thermometer for the two weeks under consideration.

SUMMARY OF RESULTS OF EXAMINATIONS OF SERIES I.

April, 1887.	8-9	9-10	1-2	2-3	6-7	8-9	10-11	Average K. J. in mm.	Total No. of Examinations.	Total No. of Experiments.	Mean Barometer.	Mean Thermometer.
1st..........	36	88	111	68	49	44	45	63	7	149	30.092	34
2d...........	28	72	63	52	23	33	58	47	7	169	29.879	44
3d (Sunday)	40*	64*	39	74*	33	57**	18	47	7	178	30.022	52
4th..........	31	73	20	24	27	21	22	31	7	177	29.808	61
5th..........	19	51	27	43	..	57	23	37	6	135	30.038	38
6th.........	23	79	49	54	15	32	29	40	7	173	30.328	40
7th..........	29	71	66	34	31	52	32	45	7	175	30.477	44
8th.	22	70	29	42	44	51	43	43	7	183	30.577	46
9th..........	35	71	37	36	21	33	14	35	7	178	30.383	50
10 (Sunday)	13	53	26	44*	..	31	17	31	6	144	30.127	67
11th........	9	40	23	41	27	25	20	27	7	176	30.076	72
12th........	20	57	21	42	29	34	10	30	7	165	30.247	58
13th........	25	74	44	46	42	50	20	43	7	167	30.304	51
14th........	20	53	42	41	16	36	..	35	6	151	30.216	50
	25	65	43	47	30	40	27	40	95	2320	30.184†	50°.5‡

*The examination was one hour late.
**The examination was one hour early.
†Mean barometer for April, for 16 years, was 29.995.
‡Mean thermometer for April, for 16 years, was 53.°3.

A little study of the table tells one that the lowest averages were obtained in examinations taken at the beginning and end of each day. Inasmuch, however, as the first examination was made when the subject was just out of bed and still half asleep, while all the rest were made after he had been thoroughly roused, it would seem that the first examination, though of great interest, could scarcely be compared to the rest. Of the six remaining examinations, the one taken immediately after breakfast has, usually, decidedly the largest average. There are exceptions to this rule, however; thus, on April 1st the highest average was got at 1.15 P. M.; on April 3d at 3.30 P. M ; on April 5th at 7.45 P.M; and on April 11th at 2.30 P. M. No cause suggests itself why an exception to the rule should have occurred on April 1st, unless, indeed, some unusual excitement prevailed at the time of the examination. The same may be said of April 3d; this day was Sunday, however, and the change of hours and the absence of hard work in the morning may have influenced the result. On the 5th of April, the disturbing cause was without doubt the weather. The barometer, which was low in the morning, as can be seen by referring to the table of the day, rose, and the temperature fell as the day advanced. Later in the paper it will be shown that such changes are potent influences and always tend to increase the extent of the knee-jerk. With regard to April 11th, it can only be said that the journal reports that there was a seminal emission early in the morning. Whether this fact accounts for the depression of the averages early in the day cannot be definitely decided. In spite of the exceptions noted, it is just to

say that the knee-jerk is generally highest in the early part of the day. This conclusion corresponds with the feeling of the subject, who is usually most vigorous in the early part of the day, but who occasionally does not feel like active work until considerably later.

The last line of the table contains the averages derived from all the experiments taken at each of the regular examinations, arranged according to the hours at which the examinations were made. These averages corroborate what has been already stated, that there is a diurnal variation of the knee-jerk, that it is greatest in the morning, just after the first meal, and that it is lower at night. This falling off of the knee-jerk can be scarcely attributed to anything except a depression of the condition of the body as a whole dependent on weariness, and, as far as the writer can judge, it is proportional to the degree of fatigue, except when counteracted by some reënforcing influences. Although the knee-jerk tends to become less as the day goes on, one sees in the averages given at the bottom of the table, viz.: 25, 65, 43, 47, 30, 40, 27, that the decline is an interrupted one, and this brings us to the consideration of the effect of hunger.

THE EFFECT OF MEALS ON THE KNEE-JERK.—It may be stated, as a rule, that the knee-jerk is higher after each meal than before it. This rule, however, like every other, has its exceptions, and they are shown in the following table :

Explanation of the Table.—In this table the average knee-jerk, before and after each meal, is given, and in the columns following the difference between

these averages is placed under the sign +, if the knee-jerk was greater after the meal, and under the sign —, if it was greater before the meal.

EFFECT OF MEALS UPON THE KNEE-JERK.

DATE.	BREAKFAST.				LUNCH.				DINNER.			
April, 1887.	Before.	After.	+	−	Before.	After.	+	−	Before.	After.	+	−
1st........	36	88	52	....	111	68	..	43	49	44	..	5
2d..........	28	72	44	....	63	52	..	11	23	33	10	....
3d (Sunday)	40	64	24	....	36	74	38	....	33	57	24	....
4th.........	31	73	42	....	20	24	4	....	27	21	..	6
5th.........	19	51	32	....	27	43	16	....	..	57	..	....
6th.........	23	79	56	....	49	54	5	....	15	32	17	....
7th.........	29	71	42	....	66	34	..	32	31	52	21	....
8th.........	22	70	48	....	29	42	13	....	44	51	7	...
9th.........	35	71	36	....	37	36	..	1	21	33	12	....
10 (Sunday)	13	53	40	....	26	44	18	....	..	31	..	....
11th........	9	40	31	....	23	41	18	....	27	25	..	2
12th........	20	57	37	....	21	42	21	....	29	34	5	....
13th........	25	74	49	....	44	46	2	....	42	50	8	....
14th.... ...	20	53	33	....	42	41	..	1	16	36	20	....
	25	65	40		43	47	4		30	40	10	

From the table, one learns that the knee-jerk was always greater after, than before, breakfast. As has been said, however, this comparison is scarcely just, because the subject was not fully awake at the time of the first examination. One also sees that the average was greater after than before lunch, on nine of the fourteen days studied; that on two more days, the 9th and 14th, there was only the dif-

ference of one mm. between the averages of the two examinations, and that on three days, the 1st, 2d and 7th, the average was considerably greater before than after lunch. With regard to the effect of dinner, one observes that the average was greater after than before dinner on nine of the twelve days on which both examinations were made, that it was only two mm. greater before than after dinner on one of the remaining days, the 11th, and that it was 5 mm. and 6 mm. greater before than after dinner on, respectively, the 1st and the 4th.

As everyone knows, the result of a hearty meal is to make one feel quiet and indisposed to work, while the effect of a moderate meal is to rest and invigorate. If one has been working hard up to the moment of meal time, the tire is at first unnoticed, because the excitement still remains, and it is only after an interval of quiet that one becomes conscious of the weariness. Inasmuch as the activity of the mind has a great influence upon the extent of the knee-jerk, as will be shown hereafter, it is probable that the mental condition is in a great degree responsible for the exceptions which have been noted. An examination of the averages derived from all the experiments taken during the two weeks, before and after the three meals, is to be found at the bottom of the table, and it shows that the knee-jerk was, on the average, always greater after, than before, each of the three meals. It may be justly stated, therefore, that the effect of a meal is to increase the knee-jerk, but that this tendency is not so strong but that it is frequently overcome by counteracting influences.

It may be well to note here that no wine or beer

was used with the meals, but that coffee was taken with breakfast and dinner, and tea with lunch.

EFFECT OF MUSCULAR FATIGUE UPON THE KNEE-JERK.—As has been shown, the knee-jerk, by its diurnal variations, illustrates the gradual loss of vigor which the body, as a whole, suffers from morning till bed time, and the temporary and partial recoveries which it undergoes, as a result of the fresh supplies of nutriment and of rest which it obtains at each meal.

The phenomenon is still more markedly affected by the voluntary exercise of the muscles which are directly concerned in its production. A proof of this statement is offered in the experiments recorded in the following table:

Time of Exam.	Extracts from Journal.	Average Knee-Jerk.
11 A. M.	After writing half hour	71 mm.
11.15 A. M.	After walking up and down stairs 15 min.	28 mm.
11.45 A. M.	After talking earnestly	32 mm.
1 P. M.	After studying curves an hour	44 mm.
2.15 P. M.	Just after lunch	46 mm.

Here one sees that the effect of walking up and down stairs for fifteen minutes was to decrease the average extent of the knee-jerk from 71 mm. to 28 mm. There can be no doubt but that the change was the result of the exercise, for during the next two hours of quiet the average gradually increased, in spite of the fact that hunger and general fatigue must have tended to lower it. Numerous illustrations of the decrease of the knee-jerk, as a result of the voluntary exercise of the muscles of the leg, have occurred in the course of our experiments; thus, we have always found that the phenomenon was markedly decreased by a walk or even a short stroll. This observation is of importance to the

practicing physician, because it teaches him not to expect a vigorous knee-jerk from a patient who has walked a mile to his office.

How far the lessening of the movement seen in such cases is due to fatigue of the muscles which extend the knee, and how far it is dependent on fatigue of the central nervous mechanisms, is a problem, the solution of which would require a special research, which we have as yet had no time to undertake. That the extent of the knee-jerk is intimately dependent on the activity of the spinal centers cannot be doubted, and this dependence probably accounts to a great extent for the diurnal variations which we have called attention to, but it is not at all clear that it is the wearying of the spinal centers which accounts for the low knee-jerk which is found to result from a walk.

Effect of Mental Fatigue.—In our experiments we find that the brain exerts an indirect, but nevertheless very considerable, influence over the extent of the knee-jerk, as will be shown when we come to study the subject of reënforcements. It is rarely, if ever, that the mechanisms of the brain act singly, and consequently it is most difficult to trace the reënforcing influences to their proper source. Apparently, however, it is those centers which are the seat of the will, and of the emotions, rather than those by which we perform such forms of mental work as adding, memorizing and planning, that are chiefly concerned in reënforcing the knee-jerk. In our experiments we have not found that short periods of mental work have any effect on the extent of the knee-jerk, and when the work extended

over long intervals the effects of hunger and of general fatigue disguised the results.

UNUSUAL MENTAL FATIGUE.—Twice in the course of the experiments the subject spent too many hours in measuring and tabulating results, and the work, together with the depressing weather which prevailed at the time, caused unusual mental fatigue. The weariness showed itself in a slight dizziness and an irritability which made him start at unexpected noises. During the experiments which were made at this time the peculiar sensation in the muscle, resulting from the jerk produced by the blow, or from the sudden contraction of the muscle, a feeling which was ordinarily unnoticed became so acute and so disagreeable that toward the end of the examination it was hard for the subject to lie quietly. He had a strong desire to contract the muscles of the limb and foot of the side experimented upon, the feeling being comparable to that which one has in the muscles of the jaw after biting a piece of rubber hard. The more one thought of it the stronger became the temptation to move, until it seemed to the subject as if he were keeping quiet by a positive act of the will. This nervous desire to contract many muscles of the limb was suggestive of a central rather than a peripheral excitability, and at first thought was referred to the spinal cord. The idea suggested itself that the brain was weary and was therefore unable to exert the inhibiting influence which many suppose it to have over the centres of the cord, and that these centres being partially freed from control, were unusually active. The subject found, however, that by directing his thoughts away from the experiments and to other subjects, by compelling himself to give

his whole attention to planning an apparatus, for instance, he could, after a little time, forget the irritating sensation. When the thoughts were thus engaged on other matters, it would seem that the spinal cord would be more free from cerebral control than when the mind was wholly interested in the knee-jerk, and yet the disagreeable sensation and the exaggerated movements ceased, which proved the excitability to be in the brain rather than in the cord. It was never found during this research that it was possible to inhibit the extent of the knee-jerk by an act of the will, but the subject noticed again and again that when the knee-jerk was being reënforced by unusual cerebral activity, especially if of an emotional character, the extent of the movement could be reduced by directing the thoughts to some indifferent subject, for instance, by quietly concentrating the attention on the warmth of the skin of the hand.

As far as the writer can judge, from his experiments, fatigue, whether bodily or mental, is accompanied by a decrease of the knee-jerk, and the exceptions recorded above, when excessive mental weariness was found to increase the extent of the phenomenon, was due to the fact that the mind was in an irritable condition, and reënforced the knee-jerk. This matter will become clearer after a review of the ways in which the knee-jerk can be reënforced.

[Since the above was written the attention of the author has been called to a short article by Maximilian Sternberg, in the Centralblatt für Physiologie, May, 1887, in which the writer relates his experiments, and states his conclusion that an increase of the tendon reflex is a sign of general fatigue, whether produced by long-continued physical or mental exertion, and explains the fact as possibly resulting from the withdrawal of cerebral inhibition. This result is the opposite of that reached by the author of this

paper. The apparent contradiction, however, may be explained by the fact that Sternberg's experiments dealt with cases of extreme fatigue, while those of the author were confined to a study of an amount of fatigue such as would ordinarily occur in the course of a day. The whole subject of the effect of different kinds and of different degrees of fatigue on the knee-jerk, is worthy of further study.]

REËNFORCEMENTS OF THE KNEE-JERK.—As has been said, successive blows of the same force, delivered at like intervals, and on exactly the same part of the ligamentum patellæ, called forth knee-jerks of different strengths. Since the stimulus was the same in each case, the causes of the variations must be sought within the individual. It immediately suggests itself, that it is possible that the irritability of the muscle is continually undergoing change. When one, however, considers how equally a muscle which has been separated from the influence of the central nervous system, by division of its nerve, responds to like stimuli, he is forced to admit that the variations in the knee-jerk must result from changes originating outside of the muscle, and, most probably, in the central mechanisms with which it is connected. If the knee-jerk be a reflex act, as many suppose, its variations may well be due to alterations in the activity of the reflex centers of the cord; if it be a peripheral act, it may be that the variations are dependent on changes in the tension of the muscle, resulting from changes of activity of the centers of the spinal cord, which are thought to control its tonus. In fact, whatever the nature of the process resulting in the knee-jerk, one must look to the centers of the spinal cord as the source of the variations which have been noticed. What are the influences which determine the activity of these centers? It is wisest

to not try to answer this question, and to attack the subject from another side.

As has been said, it was not the object of our research to determine the causes of the reënforcement of the knee-jerk, but we soon found that we could not study the subject at all without taking this question into consideration. It is not too much to say, that every knee-jerk which one obtains, is the resultant of a vast number of reënforcing influences, which are for the most part unrecognizable, but which occasionally reveal themselves, though singly, when some source of reënforcement is so active as to attract attention.

Reënforcement Caused by Irritation of the Skin.—For instance, a sensory irritation, such as a prickling or itching of the skin, causes a marked reenforcement. Thus, at the examination at 6.30 P. M., April 5th, the average knee-jerk was 14 mm., and the reënforcement which resulted from a blow which chanced to be given at the moment when the ear itched was 63 mm. (Fig. 4.) Again, at the examination at 12 P. M., on April 12th, the average knee-jerk was 13 mm., and itching of the skin caused a group of reënforcements, viz: 37, 14, 25, 25, (Fig. 5.) With regard to the extent of the reënforcements, one must remember that even when an irritant is con-

Fig. 4.

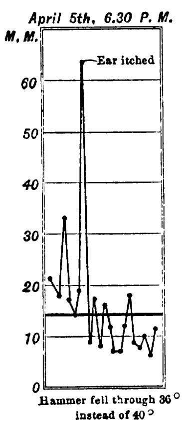
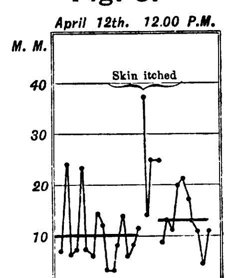


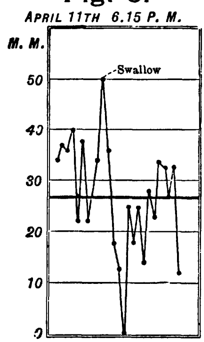
Fig. 5.



tinuously applied, we recognize the sensation, not as constant, but as of varying intensity, and that Mitchell and Lewis found that the extent of the reënforcement depended upon the moment at which the blow was delivered. If the blow falls at the moment that the reënforcing influence is at its height, the resulting movement is more marked than if the knee-jerk is called out a little earlier, or a little later. Thus, in the second example given, the skin was itching all the time, but the intensity of the sensation was much greater at one moment than at another, and the reënforced knee-jerks show a similar difference. The above examples illustrate a fact which was demonstrated many times in the course of our experiments. It was noticed, again and again, that not only such a positive source of irritation to the skin, but anything causing discomfort, as, for instance, a crease in the clothing, or an uncomfortable position, was sufficient to increase the extent of the knee-jerk. These observations corroborate the results of Mitchell and Lewis, who found that painful impressions brought to the skin, as heat, cold, the electric wire brush, etc., were capable of reënforcing the knee-jerk.

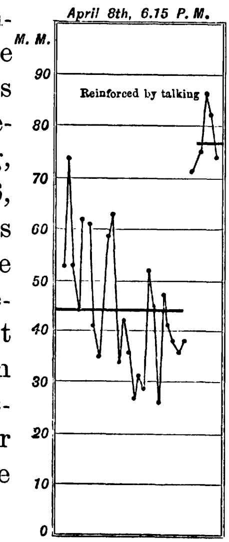
REËNFORCEMENTS PRODUCED BY VOLUNTARY ACTIONS. Mitchell and Lewis also found that any voluntary movement, however slight, tended to reënforce the knee-jerk, and in our experiments we saw this fact illustrated over and over again. Thus at the examination at 6.15 P. M., on April 11th, the average knee-jerk was 27 mm., and the movement which resulted from a blow which chanced to fall at the moment the subject was swallowing, was 50 mm.

Fig. 6.



(Fig. 6.) Again, at the examination at 6.15 P. M., on April 8th, the average knee-jerk was 44 mm., and the knee-jerks which were called out immediately after the regular experiments and which were reënforced by talking, measured 71, 75, 86, 82 and 74 mm. (Fig. 7.) As has been said, to get the full effect of the reënforcement, the blow must be delivered at just the right moment after the reënforcing act. When this was done, such active reënforcing acts, as clenching the hands or teeth, enormously increased the movement. (See fig. 4.)

Fig. 7.

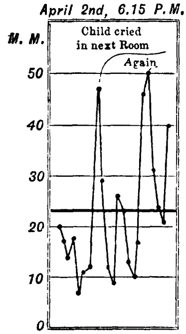


Reënforcements Produced by Exciting the Attention.—All these reënforcing influences were of interest to us chiefly because of our wish to avoid them, and our desire to see blows of the same force call forth knee-jerks of the same extent. When the subject was lying entirely quiet, with closed eyes, in what he felt to be an absolutely comfortable position, the knee-jerks continued to be of variable extent. A cause for some of these variations was, however, soon discovered. During the examination at 6.15 P. M., April 2d, a child in the next room began to cry, but was immediately quieted; in a few moments the child began to cry again and was again quickly quieted. The average

knee-jerk at this examination was 23 mm., and the movement which occurred while the child was crying were 47 mm. and 46 mm. (Fig. 8.) The subject of the experiments was in no way interested in the child and was not conscious of making the slightest movement while it was crying.

Fig. 8.

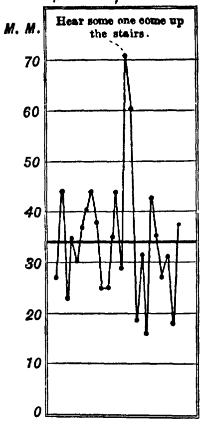
April 2nd, 6.15 P.M.



Three explanations of the reënforcement suggested themselves: One, that the subject had, without knowing it, made a voluntary movement; another, that the sound had acted like other forms of sensory stimulation, which have been found to reënforce, and, finally, that it was possible that the cerebral processes, which accompany the turning of the attention into new channels had, in some way, influenced the action of the distant centres in the cord which control the extent of the knee-jerk.

When the attention of the subject had once been turned to studying the action of his mind, he began to recognize that the activity of his thoughts was not without an influence on the extent of the knee-jerk. It was soon noticed that noises which were not loud, and which could be only very weak sensory irritants, if of a kind to attract the attention, increased the extent of the phenomenon, while much louder sounds, if devoid of interest, had no appreciable effect. Thus, during the examination at 8 P. M., April 12, when the average knee-jerk was 29 mm., some one was heard coming up stairs, and the knee-jerks, which happened to be taken at the time,

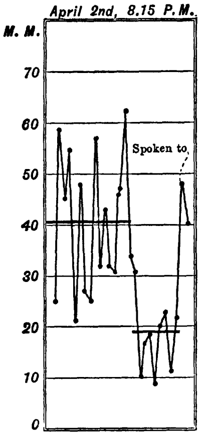
Fig. 9.
April 12th, 8.00 P. M.



were 71 mm. and 60 mm. (Fig. 9.) At the same time, the rattling by of carts, an accustomed sound, and one devoid of interest, had no appreciable effect. It was soon found that if the subject were spoken to, if a knock came at the door, or if in any other way the attention of the subject were attracted at the moment that the blow was struck, the knee-jerk was markedly increased.

EFFECT OF CEREBRAL INACTIVITY AND OF SLEEP. If the sudden awakening of the attention was capable of increasing the knee-jerk it might seem as if a quieting down of cerebral activity would produce the opposite effect, and this appeared to be the case. Not infrequently the average of the experiments at the beginning of an examination, when the mind of the subject, who had perhaps just stopped working, was in an active state, was considerably higher than the average of the experiments which were made toward the close of the examination, when quiet, or even a condition closely resembling sleep, had crept on. It is, perhaps, worth noting that the subject has always had the faculty of going to sleep at short notice, and that the jars caused by the regular blows of the hammer ceased to attract his attention after a few hundred experiments had been made upon him. The effect of the quieting down of the cerebral mechanisms was illustrated in the examination at 8.15 P. M., April 2, when the average of the first fifteen experiments was 41 mm. and the average of the next

Fig. 10.

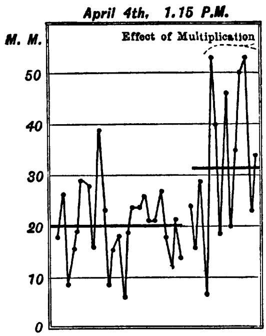


ten experiments was 19 mm. The next two blows were struck just after the subject had been spoken to, and the knee-jerks were 48 mm. and 40 mm. (See Fig. 10; see, also, Fig 9 and Fig. 6.)

Effect of Different Forms of Cerebral Activity.—The experiments which we made with reference to the effect of different forms of cerebral activity were far too few to offer a basis for positive conclusions, but it seemed to us that it was the emotional forms of activity which had the greatest influence on the process. Thus, in the case of mental arithmetic, the simple act of multiplying two numbers, even if they were difficult, did not seem to affect the knee-jerk especially, unless the endeavor was made to obtain the result as quickly as possible and the subject were excited by the attempt. The question is worthy of an especial research. One great difficulty in such a research arises from the fact that the experimentor cannot time the blow so as to get the knee-jerk at the moment when the mind of the subject is most actively employed. It is possible that such experiments might be combined with plethysmographic experiments to advantage.

Effect of Multiplication.—At the examination at 1.15 P. M., April 4th, we tried the effect of multiplication. The average knee-jerk at the time was 20 mm., while the average during the period

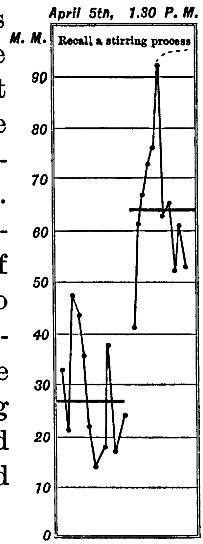
Fig. 11.



when the subject was rapidly multiplying, was 32 mm. (Fig. 11.)

Reënforcement Caused by Exciting Mental Work.—A good example of the effect of exciting mental work is to be found in the results of the examination at 1.30 P. M., April 5th, when the subjet repeated to himself Browning's stirring poem—"How they Brought the Good News from Ghent to Aix." The average knee-jerk during the preceding quiet had been 27 mm., and the average taken while the poem was being recalled to memory was 64 mm. (Fig. 12.) In such a case as this, one cannot help thinking that the muscles of the larynx may have been called into play, and that the rhythm of the respiration may have been altered. The subject was not conscious of making any attempt at phonation, but it did seem to him that his breathing had been longer and deeper.

Fig. 12.



Effect of Respiration on the Knee-Jerk.—It is interesting to consider, in this connection, the effect of the respiration on the knee-jerk. A few experiments were made with reference to this point, the respiration and the knee-jerk both being recorded on the same moving surface. It was not found in these experiments, however, that the res-

piration had any effect upon the phenomenon. It seemed to make no difference whether the blow fell at the beginning, middle or end of inspiration, or at the beginning, middle or end of expiration. In fact, as far as these experiments gave information, the regular acts of respiration do not reënforce the knee-jerk.

Renëforcement Produced by Asphixia.(?)—The following experiments show that the knee-jerk is not altered by slight changes in the respiratory rhythm, but that it is increased by violent respiratory movements, or the causes which produce them. In the examination made at 8.30 P. M., April 8th, the average knee-jerk was 51 mm. The following experiments were made fifteen minutes later, and in just the same way, except that the blows were delivered at intervals of ten, instead of fifteen seconds, the usual rate. The figures show, as in all other cases, the extent of the movements of the foot, resulting from the knee-jerk, in millimetres.

During quiet—35, 29, 55—a deep inspiration is taken, and the breath is held for seventy seconds—41, 44, 45, 49, 55, 72, 100—breathe again, and at first very hard—72, 57, 61, 42, 41, 52, 41, 32—another deep inspiration taken, and held seventy seconds—56, 58, 67, 70, 78, 79, 89—breathe again, and heavily—80, 59, 64, 56, 41, 30.

The first time the breath was held, more than forty seconds elapsed before a material increase in the extent of the knee-jerk was seen, but during the next thirty seconds, when the endeavor to keep from breathing had become painful, the increase in the knee-jerk was very marked. As soon as the subject

began to breathe again the irritation began to pass off, and the movement to become less, and in about forty seconds it had got back to its normal average.

When the breath was held the second time, the increase in the knee-jerk came much sooner, and as in the first case, the extent of the movement increased as the feeling of oppression increased. As in the previous case, it required about forty seconds after breathing had begun again, for the knee-jerk to get back to its normal amount.

How far the increase in the phenomenon seen in these experiments was due to the pain, and how far to the effects of temporary asphixia upon the central nervous system, is difficult to say.

Similar results were got when the breath was, as far as possible, expelled and kept out. During quiet—52, 41, 47, 46, 41—breath expelled and kept out—65, 80, 85, 99—breathe again—72, 80, 60, 69, 63, 67, 44. This was a much more painful experiment, and the effect of the lack of air was perceptible almost at once in the increase of the knee-jerk. At the end of forty seconds the pain was so intense as to bring tears to the eyes, and even after the breath was taken again, the painful feeling referred to the lower part of the chest lasted for some time. It is noticeable that in this case the knee-jerk returned to the normal more slowly than in the previous experiments.

These experiments are recorded here not because any definite conclusion can be drawn from them alone, but because they are suggestive, and because they illustrate one more of the many sources of reënforcement of the knee-jerk. Whether they should be grouped with reënforcements which result

from painful sensory impressions, from voluntary actions, from emotional activity, or from functional disturbance of the spinal centers, is hard to say, since all these causes seemed to take part in producing the result.

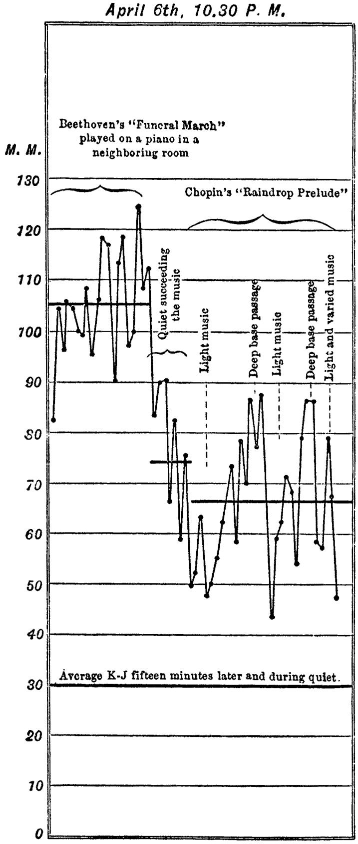
Reënforcement of the Knee-Jerk Caused by Music.—Perhaps the most interesting of all the forms of reënforcement attributable to cerebral action, which we saw, was that produced by music. Not all forms of music have this power, however, and, as far as we have been able to judge, it is confined to such as are capable of exciting an emotional interest. For instance, the writer can state that "Beautiful Spring," when played by a hand-organ, has little or no effect upon his knee-jerk, although a good military band, when playing a stirring march, is able to cause a very decided reënforcement.

One day during the experiments a procession passed the end of the street, a short distance away, and the effect of the music was very evident. The twenty-five experiments of the examination which had just been made had shown the average knee-jerk to be 32 mm. At the approach of the procession the subject resumed his place on the apparatus, but the first blow was not struck until the first band was passing the end of the street—60, 71, 74, 70, 60, 55—another band immediately followed, and it began to play "My Maryland" just before it reached the street—62, 76, 76, 74, 71, 66, 59, 64, 59—this was followed by a drum corps—48, 55, 51, 55, 53, 49, 52—and then the music died away in the distance and only the ordinary street sounds remained—40, 45, 37,

30, 39, 53, 37, 29. The increase and decline of the knee-jerk as the music approached and died away, and the difference in the effect of the bands, the drum corps and the street sounds, is very interesting. The fact that the character of the music determined its power to reënforce the knee-jerk was still more clearly illustrated in an experiment made on April 6. The average knee-jerk at 8 P. M. was 32 mm. and the average knee-jerk at 11 P. M. was 29 mm. It is fair to assume that at 10.30 P. M., the time of the experiment, the average knee-jerk during quiet would not have been far from 30 mm. The music used in this experiment was a good piano in a neighboring room, played by a skillful pianist. While Beethoven's "Funeral March" was being played the knee-jerks were, viz.: 82, 104, 96, 105, 104, 99, 108, 95, 106, 118, 117, 90, 113, 119, 97, 100, 124, 108, 112, and the average was 105. This was followed by an interval of quiet, during which the knee-jerks fell off—83, 90, 90, 66, 82, 59, 75, 50; average, 74. Then Chopin's "Raindrop Prelude" was played, and to our delight, when we came to read the results we found that the extent of the knee-jerk had varied with the character of the music in the most remarkable manner. Thus, during the soft music, when the raindrops are supposed to be falling, the knee-jerk was 52, 63, 47, 50, 55; as the music changed and the deeper passages began to make themselves felt, it was 66, 73, 58, 78, 70, 86, 77, 87; as the music subsided and became softer the measurements were 66, 43, 59, 62, 71, 68, 54; as the more thrilling passages succeeded 79, 86, 86 was measured, and finally, as the varied but softer parts came again, the knee-jerk was 58, 57, 79, 67, 47. As has been said, the average of the knee-jerk during

Fig. 13.

April 6th, 10.30 P. M.



quiet, as found by twenty-five experiments taken a short time after the subject had quieted down, was 29 mm. (See Fig. 13.)

Perhaps the reader is inclined to doubt that music could have had such an effect, and may wonder, as did the writer, whether it were not possible that the subject of the experiments had unconsciously favored, or, perhaps, even almost manufactured the results. That this was the case, however, scarcely seems probable, because the subject was never sure during the examinations of the extent which his foot moved, excepting to know that the movement was slight or was considerable, and he was unaware of the closeness with which the knee-jerks had followed the music until he saw the curves after the experiments were over. Had this been the first set of experiments which had been made on the subject it is probable that he would have been much more interested in the blows of the hammer than in the music, but as this was the sixth day of the series, and as his knee had been struck more than a thousand times during

the week, he was able to forget the blows of the hammer and to think only of the music.

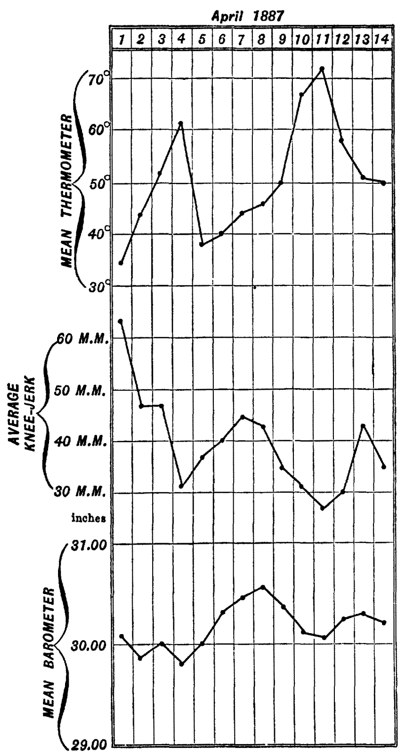
REËNFORCEMENTS PRODUCED BY EXCITING DREAMS. The fact that the amount of the knee jerk is largely dependent on the activity of the cerebral centers, which are the seat of the emotions, has received another and curious illustration in the course of our experiments. As has been said, the subject, when tired, not infrequently dozed off toward the end of an examination, or, at least, so far lost consciousness that he became no longer responsible for his thoughts. Thus, it not infrequently happened that he pictured himself as kicking a football, or straining to lift a heavy weight, or steadying himself to aim a pistol, or as performing some other vigorous action, and if, as was not seldom the case, the blow on the ligamentum patellæ was struck at such a moment, he was recalled to himself by the unusual violence of the resulting knee-jerk. This was not a single experience, but happened many times, so that the subject had no doubt of the correctness of the observation.

Even during sleep, then, cerebral activity is making itself felt throughout the body. This fact scarcely needed a proof, for every one has noticed the running movements of sleeping dogs, etc. It is interesting in this connection, however, because evidence thus obtained is much more trustworthy than any which could be gained during waking hours, when the subject might be thought unintentionally to help to bring about the results.

INFLUENCE OF THE WEATHER UPON THE KNEE-JERK. —In the course of the experiments the subject noticed that his general condition and his knee-jerk were be-

coming less vigorous and attributed the change to the fact that the weather was becoming warmer. The first warm spring days give most men a feeling of lassitude, and the subject knew that he was no exception to the rule. One's sensations are unreliable data, unless corroborated by more substantial evidence, and it seemed worth while to compare the recorded variations of the knee-jerk with the variations of the temperature during the two weeks. The U. S. A. weather observations were accordingly consulted, and it was found that, in general, as the temperature increased the knee-jerk became less. The correspondence was not so close, however, but that it was evident that other influences were at work, and it occurred to the writer that the barometric changes of the atmosphere might be of importance in this connection. How greatly the extent of the knee-jerk is influenced by thermometric and barometric changes can be best understood by study of Fig. 14.

Fig. 14.



Explanation.—At the head of the chart is written the dates on which the experiments were made, and at the left side the

Farenheit thermometer scale from 30°–70,° a scale of millimetres, to show the extent of the knee-jerk, and the barometer scale from 29–31 inches. The curve opposite the thermometer scale shows the variations of the temperature, each of the dots connected by the lines giving the mean temperature for the corresponding day. The curve opposite the millimetre scale shows the variations of the knee-jerk, each dot representing the average of all the experiments taken on the corresponding day. Similarly the curve opposite the barometer scale records the variations of the barometer, each dot giving the mean of the barometer for the corresponding day.

STUDY OF THE DIAGRAM.—The correspondence between the temperature and the knee-jerk curves is not very accurate, but one sees that on the 4th and 11th, when the temperature was high, the knee-jerk was low, while on the 1st, 7th and 14th, when the thermometer was much lower, the knee-jerk was considerably higher. In general, then, as the temperature rises, the knee-jerk becomes less, and as the temperature falls, the knee-jerk becomes larger.

If now one compares the knee-jerk and barometer curves, he finds the agreement to be much closer. The barometer fell, roughly speaking, from the 1st to the 4th, so did the knee-jerk; the barometer rose from the 4th to the 8th, so did the knee-jerk; the barometer fell from the 8th to the 11th, so did the knee-jerk; the barometer rose from the 11th to the 13th, so did the knee-jerk; and finally, the barometer fell from the 13th to the 14th, and so did the knee-jerk. In general, then, it may be said that as the barometer rises and falls the knee-jerk rises and falls.

A more careful examination, however, shows that though this general correspondence existed, the two did not agree in the extent of their variations, nor did they vary in just the same way from day to day. Thus the knee-jerk fell markedly from the 1st to

the 4th, and the barometer fell only a little; moreover, the barometer rose from the 2d to the 3d, while the knee-jerk was stationary. Again, one sees that the knee-jerk fell off from the 7th to the 8th, although the barometer was still rising. These differences can only be understood by simultaneously comparing the three curves, and remembering that a rise of temperature or a fall of the barometer tends to depress the knee-jerk, while a fall of temperature or a rise of the barometer tends to elevate the knee-jerk curve.

From the 1st to the 2d the temperature rose and the barometer fell, and both of these influences acted to lessen the movement; from the 2d to the 3d the temperature continued to rise and the barometer rose, and the counteracting influences caused the knee-jerk to remain stationary; from the 3d to the 4th the temperature rose and the barometer fell, and the knee-jerk curve consequently fell very low; from the 4th to the 5th the temperature fell markedly and the barometer rose a little, and the knee-jerk began to recover; from the 5th to the 7th the barometer rose markedly, and the slight rise of temperature which occurred, not being sufficient to counteract its influence, the knee-jerk curve rose; from the 7th to the 8th the continually increasing temperature began to make itself felt, so that the process became less active, in spite of the fact that the barometer continued to rise; from the 8th to the 11th both the temperature rose and the barometer fell, so that the knee-jerk was greatly depressed; from the 11th to the 13th the temperature fell and the barometer rose, and both influences assisted to restore the knee-jerk; from the

13th to the 14th, however, the barometer began to fall again, and the temperature being nearly stationary, the knee-jerk was again depressed.

These curves show most clearly that the knee-jerk is closely dependent on changes in the weather, but, inasmuch as we are something more than weather-gauges, the variation is qualitative rather than quantitative. The fact that other influences are at work is shown in the course of the curve of the knee-jerk, when looked at as a whole. Thus one observes that the general condition of the subject, when looked at from this standpoint, was falling off during the two weeks, in spite of the fact that the barometer was, on the whole, rising : moreover, this depression of the knee-jerk would seem to be greater than the rise of temperature, which occurred during this time, could account for. The fact is easily explained ; the work involved in the research and in the study of the records gained in the experiments was not small, and the fatigue which the subject felt at the end of the fortnight was an undoubted element in causing the marked falling off of the knee-jerk.

It is no new discovery that the general condition of man is greatly influenced by changes of the weather, but a demonstration of the fact is nevertheless valuable and may perhaps drive home the lesson already learned by physicians and surgeons in their practice.

It naturally suggests itself that what we call the weather is composed of other conditions beside those recorded by the thermometer and the barometer, and that the direction of the wind, the degree of humidity of the air and the electric potential of the atmosphere

may well have an influence upon man. There can be no doubt but that the degree of the humidity of the atmosphere influences us greatly by determining the evaporation of the perspiration from the skin, but that we are influenced by the electrical condition of the atmosphere is by no means as certain. One knows so little concerning the electrical changes of the air that the subject is always an attractive theme for speculation, and one is in the habit of holding it responsible, in a vague sort of way, for many peculiar feelings which he cannot otherwise explain. The idea is a popular one and even finds its way into the novel of the day. Thus, one reads: "I hastened to do as I was asked, the more readily as, what with fear and horror, and the *electric tension* of the night, I was myself restless and disposed for action."[1]

Plate II was constructed to enable one to readily compare the variations of the knee-jerk with the changes which all the different components of the weather underwent at the same time.

The study of the electrical condition of the atmosphere is a difficult one and requires the use of special appliances. The writer could, therefore, scarcely have gained any information on this point had it not been for the kindness of Mr. Park Morrill, who was making a special study of this subject near by, at the Johns Hopkins University. The curve of the electric potential of the atmosphere given in the chart is based on Mr. Morrill's figures, which state in volts the electric potential of the air as compared with that of the earth, regarded as 0.

Explanation of Plate II.—On the first line, at the top, are given the dates, and beneath them the hours of the day, from 7 A. M. to 11 P. M.

[1] The Merry Men, by R. L. Stevenson.

The first curve of the chart shows the diurnal variations of the knee-jerk as determined by seven examinations. The average of all the experiments made at each examination is represented by a dot, placed at the proper height with reference to the millimetre scale, at the left side of the chart, and under the day and hour at which the examination was made. The lines connecting the dots enable the eye to readily follow the variations of the knee-jerk during each day. The larger dots represent examinations which were made directly after a meal.

On the base line of this knee-jerk chart is recorded the direction of the wind in the morning, afternoon and evening of each day.

Below are arranged, in order, the curves which show the variations of the barometer, the thermometer, the electric potential of the air, and the relative humidity of the atmosphere. Each dot in each of these curves represents a separate observation, and is placed at a height corresponding to the scale at the side of the latter, and under the hour at which the observation was made.

The heavy cross lines show the average knee-jerk for each day, and the mean of the barometer, of the thermometer, and of the electric potential of the air for April, as determined by the observations of a number of years.

STUDY OF PLATE II.—It seems to the writer that this chart is of great value from the negative evidence which it offers. It shows that a change in the direction of the wind, a change in the electric potential of the atmosphere, and slight changes in the relative humidity of the air, are without visible influence upon the knee-jerk, and, presumably, upon the central nervous system. It also calls the attention to the fact that the variations of the barometer and the thermometer, though of the greatest importance in determining the height of the daily average of the knee-jerk, are secondary to hunger and fatigue in their effect upon its hourly variations.

SUMMARY OF RESULTS OF EXPERIMENTS OF SERIES I.—The extent of the normal knee-jerk is continually undergoing change. So great are the variations, even when the subject is at rest, that a correct idea of the activity of the process can be gained only by averaging the results of twenty or more experiments. The average knee-jerk varies in amount at different

times of day, being as a rule greatest in the morning, soon after breakfast, and being very much less at night. The decline which occurs as the day advances is very irregular, but, in general, the knee-jerk is larger after each meal. Finally, the extent of the knee-jerk may differ greatly on different days.

The causes of these variations of the knee-jerk are not only alterations in the muscles and nerves involved in the process, but, to a still greater degree, changes in the activity of the central nervous system, either as a whole or in part. Thus fatigue, hunger, enervating weather and sleep, conditions which decrease the activity of the whole central nervous system, decrease the average knee-jerk, while rest, nourishment, invigorating weather, and wakefulness, influences which increase the activity of the central nervous system, increase the average knee-jerk. These influences account for the diurnal variations of the knee-jerk, while the multitude of changes that are seen to occur within short intervals of time are due to temporary alterations in the activity of certain parts of the brain and cord. Thus voluntary movements and strong emotions, when synchronous with the blow, are found to increase the movement; and this is noticed even during sleep when the dreams are vivid. Similarly, sensory irritations, even when not strong enough to produce visible reflex actions, may markedly reinforce the knee-jerk, but whether on account of their effect upon the brain, or upon the spinal cord, must be proved by future experiments.

Inasmuch as the normal respiratory movements and quiet thought were not seen to influence the process, it seems probable that the action of the many

mechanisms of the central nervous system, except when very strong, is not accompanied by the development of reënforcing influences ; this is far from certain, however, and, inasmuch as the origin of but few of the more delicate reënforcing influences were discovered, this interesting question must be left open to future study.

In general, then, it may be said that the knee-jerk is increased and diminished by whatever increases and diminishes the activity of the central nervous system as a whole, and that it is even more noticeably altered by temporary changes in the activity of certain mechanisms of the spinal cord and brain.

In the experiments described in this paper it was found that the movements of the foot, caused by knee-jerks that were produced by the usual blow, *i. e.*, when the hammer fell through an arc of 40°, varied from 0 millimetres to 130 millimetres. Still greater movements would undoubtedly have been seen had vigorous rëenforcements occurred at the time when the average knee-jerk was higher. The average movement gained from the results of the 2,320 experiments of this series was forty millimetres. The least blow which was seen to produce a movement of the foot was obtained by letting the hammer fall through an arc of 20°.

The Results of Experiments of Series II.

The results of the experiments of Series I were so remarkable that it seemed to the writer that he ought not to publish them without assuring himself of their correctness. He accordingly undertook a second series of experiments, which extended like the first over two weeks, and which differed from

them only in this: that nine instead of seven examinations were made on each day. The two extra examinations were made, the one between eleven and twelve o'clock in the morning, the other, between four and five o'clock in the afternoon. These experiments were made with all the care that was given to the previous series, but it seems unnecessary to publish the results in detail. Suffice it to say that the conclusions reached in the second series of experiments corroborated those which were obtained in the first series in every particular. There were the same extraordinary variations in the extent of the knee-jerks produced at intervals of only a few seconds. The average knee-jerk was found to be highest soon after breakfast, and to be low at night, and it was seen to be higher after than before each meal. The extra examinations, made in the middle of the forenoon and afternoon, showed, moreover, that the average knee-jerk gradually fell throughout the forenoon and throughout the afternoon, unless some unusual counteracting influence prevailed. It was also found that the average knee-jerk changed from day to day, but the variations in the weather during this period were so slight that the other influences which determine the general condition of the individual were most active in determining the amount of the average knee-jerk. The average movement gained from the 3,156 experiments of this series was 33 millimetres. Finally, all the sources of reënforcement which were noticed during the first series were found to be active during the second.

As a proof of these statements the author appends a table which gives a summary of the results gained in Series II, the table being made on the same plan

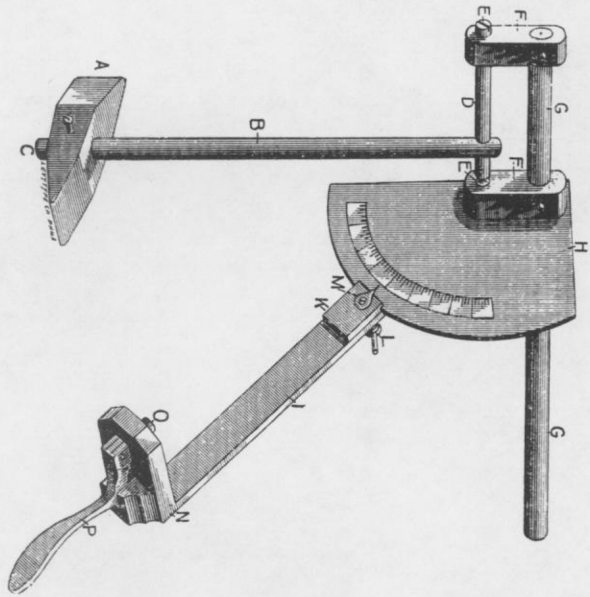
as the table on page 39, which gives the summary of the results of Series I.

Summary of Results of Examinations of Series II.

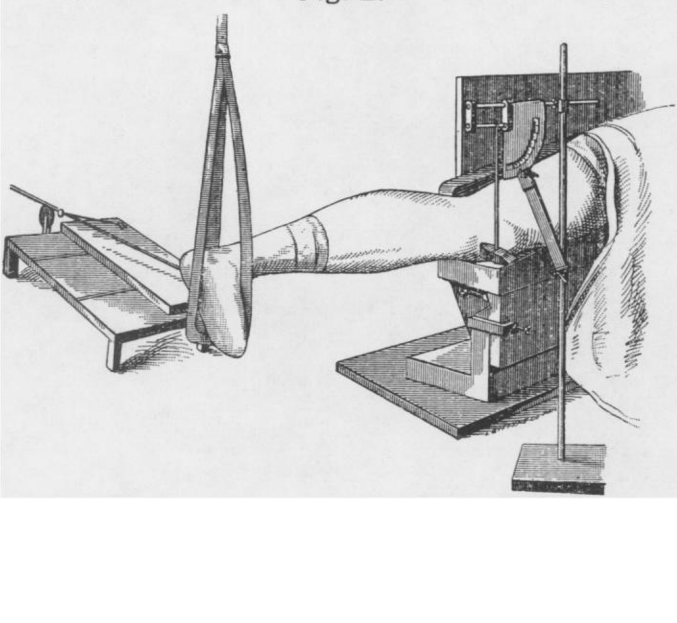
May, 1887.	7-8	9-10	11-12	1-2	2-3	4-5	6-7	8-9	10-11	Average K.-J. in mm.	Total No. of Examinations.	Total No. of Experiments.	Mean Barometer.	Mean Thermometer.
9th..........	36	43	64*	52	54	39	49	31	41	45	9	225	30.012	65°
10th..........	47	60	50	41	41	55	28	39	29	43	9	227	30.190	65°
11th..........	39	53	24	31	26	28	26	24	28	31	9	239	30.009	70°
12th..... ...	23	44	31	31	36	20	23	30	25	29	9	218	30.002	71°
13th..........	37	51	27	14	25	38	23	29	14	28	9	246	30.005	66°
14th..........	39	54	30	24	16	37	25	27	35	32	9	228	30.310	60°
15th (Sun)...	38*	43	48	43	40*	...	18	29	37	37	8	211	30.230	66°
16th..........	26	46	54	24	35	37	25	35	32	35	9	229	30.080	66°
17th..........	29	46	43	31	46	19	30	38	24	34	9	225	29.910	68°
18th..........	36	37	24	33	36	33	45	39	37	35	9	227	29.850	69°
19th..........	33	52	33	35	25	25	26	29	37	33	9	228	30.020	72°
20th..........	38	33	36	25	25	33	33	25	21	30	9	228	30.020	72°
21st..........	36	38	37	26	23	8	14	26	7	24	9	224	30.170	72°
22d (Sun)...	26*	36	20	19	29*	...	9	22	16	22	8	201	30.160	70°
	34	45	37	31	33	31	27	30	27	33	124	3156	30.069	68°

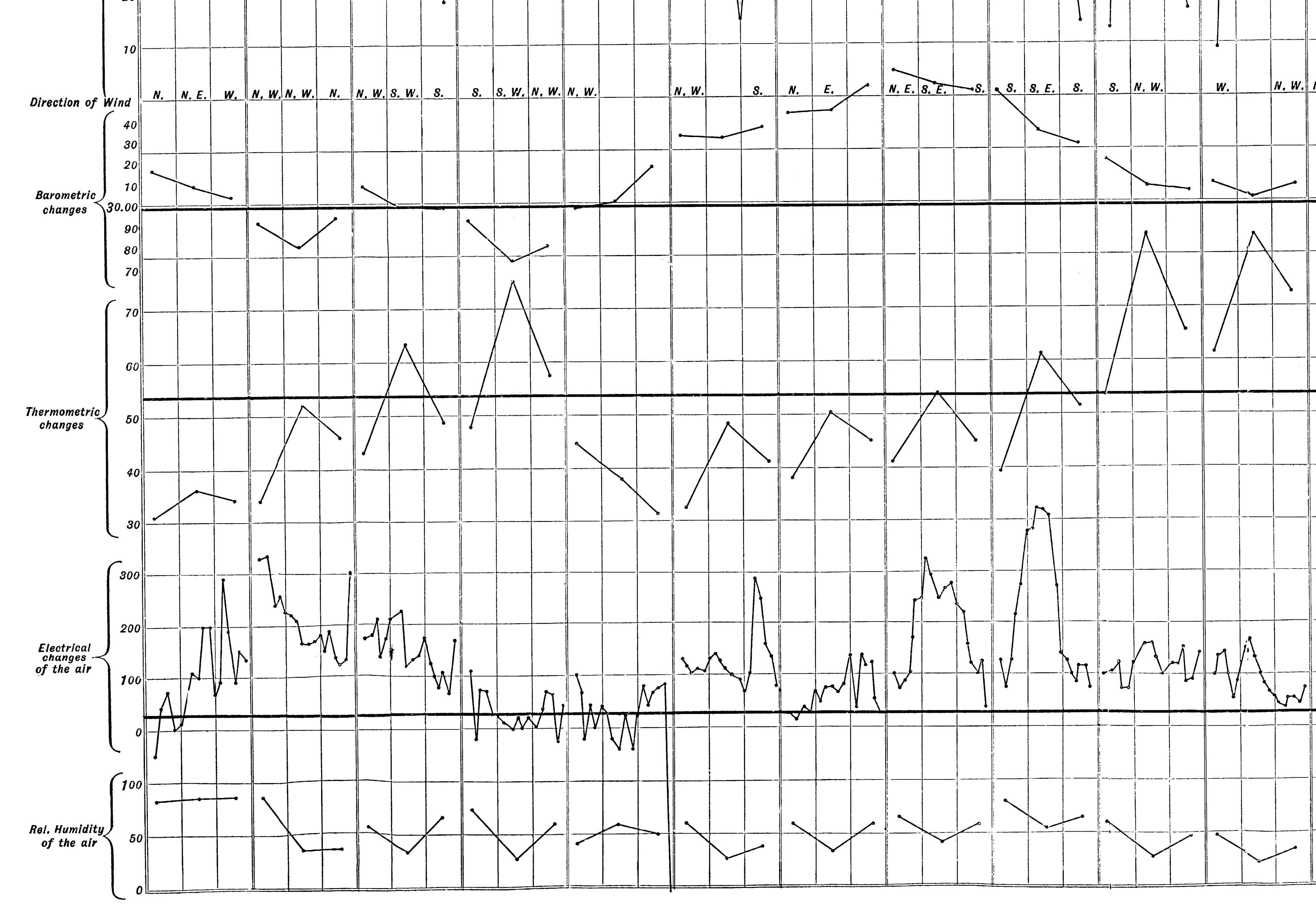
*The examination was one hour late.

PLATE I.—Fig. 1.



a Fig. 2. *b*

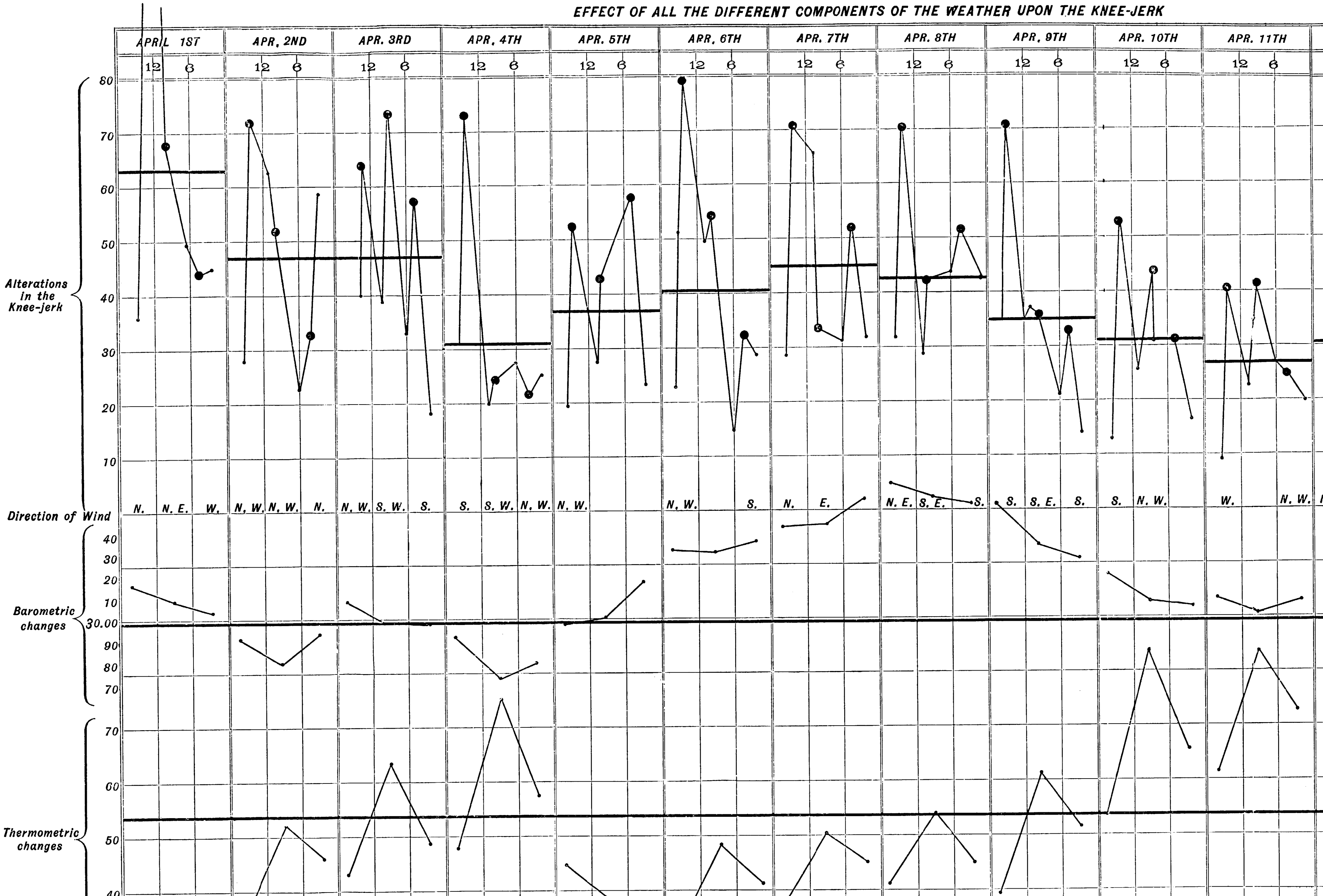


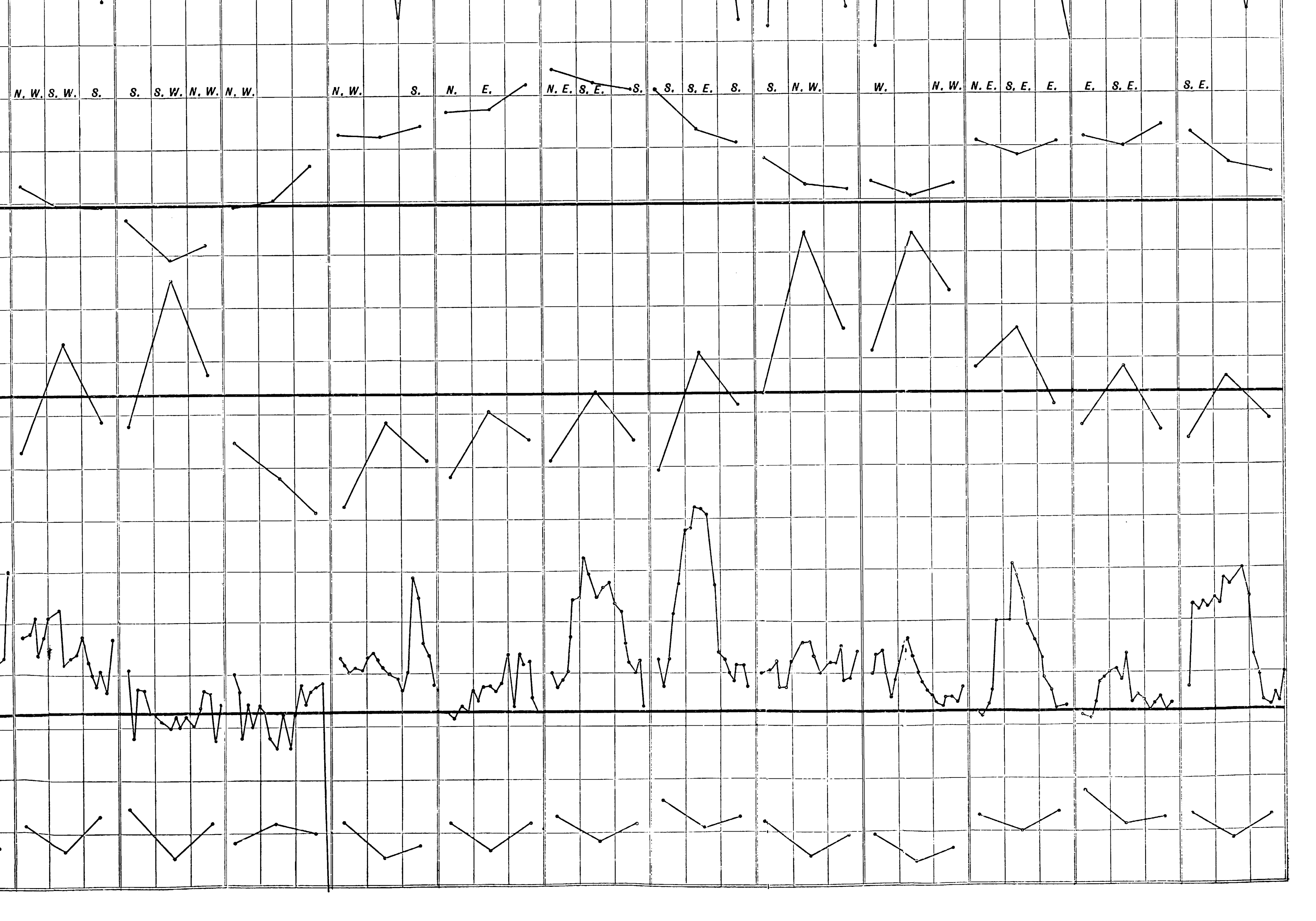


Direction of Wind
10
N. N. E. W. N. W. N. W. N. N. W. S. W. S. S. S. W. N. W. N. W. N. W. S. N. E. N. E. S. E. S. S. S. E. S. S. N. W. W. N. W.
Barometric changes
40
30
20
10
30.00
90
80
70
Thermometric changes
70
60
50
40
30
Electrical changes of the air
300
200
100
0
Rel. Humidity of the air
100
50
0

PLATE II.

EFFECT OF ALL THE DIFFERENT COMPONENTS OF THE WEATHER UPON THE KNEE-JERK

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S. E.

PLATE II.

EFFECT OF ALL THE DIFFERENT COMPONENTS OF THE WEATHER UPON THE KNEE-JERK